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Unique enclosures for bark-burning boiler at the Chickasaw Mill, Mobile, Ala., of Hollingsworth & Whitney Co.; see page 57.

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COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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Feature Articles

Editorials   ## *Departments*

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COMBUSTION

Editorials

The Second Generation for Atomic Energy

Right on the heels of the March 14 announcement that the Atomic Energy Commission had accepted the Duquesne Light Co.'s proposal to participate in the construction and operation of a 60,000-kw pressurized water reactor came the March 24 speech of Dr. Lawrence R. Hafstad, director of the AEC reactor development division, ushering in what he termed the "second generation" of power reactor development.

Speaking before the nuclear science group of the Institute of Radio Engineers in New York City, Dr. Hafstad described what he considered "one of the most refreshing things that has happened in the last five years," the development of a boiling water reactor. This reactor eliminates the intermediate heat exchanger and the need for high pressures required by the pressurized water reactor. As a result Dr. Hafstad believes piping and plumbing costs will be materially reduced and what's more the unit's operating features will permit higher temperatures at less cost and therefore higher efficiencies. (For more detailed discussion of this reactor see the Dr. Smyth report on p. 67 of this issue.) All in all a most interesting and challenging prospect.

But to our mind we see in these announcements plus Smyth's report hopes of a future in nuclear energy development that are even more promising than this single reactor. The rapid sequence with which these public AEC announcements have been made and the general tenor of their subject matter combine to assure us the AEC enjoys a healthy awareness of the value of more and greater participation by industry in this vital program of concern to all.

As a definite clincher to this line of thought we report still another public address by Eugene M. Zuckert, also a member of the AEC, before the second California meeting sponsored by the National Industrial Conference Board on March 25. Mr. Zuckert declared all members of the AEC strongly support the recommendations of President Eisenhower to Congress (COMBUSTION, March, p. 37) to change the Atomic Energy Act. The AEC feels that if adopted the law will, in fact, provide the necessary incentive to build up some momentum behind the Commission's effort.

To the above we can only add that if the changes to the Atomic Energy Act are adopted and made broad enough to be attractive on a business basis to private enterprise the "second generation" may mark one of the greatest periods in the advancement of power technology man has ever seen.

What's even more important the power industry may be able to gather enough data to permit evaluating the relative contributions to be expected from the traditional and the newer methods of energy release.

The American Power Conference In Retrospect

That good program planning is an important factor in attracting engineers to technical meetings is demonstrated by the continuing success of the American Power Conference. Now in its sixteenth year under the sponsorship of the Illinois Institute of Technology and cooperating universities and technical societies, the Conference has appealed to engineers from a much wider geographical area since changing its name several years ago from the Midwest Power Conference.

This year's program contained a wide variety of subject matter of interest to the designer, the operator and the engineering executive. Its range included steam, diesel, gas-turbine, hydroelectric and nuclear power plants. A practical flavor was introduced by the session sponsored by the National Association of Power Engineers. Many papers were presented in the fields of water technology, various phases of electrical engineering, and air conditioning. The special events included participation in Light's Diamond Jubilee Celebration and several outstanding banquet speakers.

One trend in evidence at the meeting was the increased attention given to visual presentation. A simple black and white slide showing a schematic diagram does not have the appeal of the beautiful multi-colored slides that were shown in conjunction with some of the papers. Also there were several technical papers that seemed to be staged, providing an added dramatic quality that ranged somewhere between salesmanship and entertainment. It will be interesting to see how far these trends will take hold at other engineering meetings.

With the increased size of the Conference, one evidence of growing pains was the small amount of informal discussion that took place. When audiences reach the thousand mark, as was the case in several sessions, there is understandable reluctance to raise questions from the floor. But the benefits to be derived from such discussion are such that means should be found to promote it, perhaps by making portable microphones available to the audience.

Undoubtedly the best recommendation for attendance at future conferences is to talk to any of the 2500 engineers who were present at the 1954 Conference.

Pulsation-Induced Vibration in Utility Steam Generation Units*

By RAYMOND C. BAIRD

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How a severe vibration problem in the superheater-economizer duct of a large boiler was overcome is explained in this paper. The source of the problem was determined by means of electronic measurements, a complete cure effected by the placement of simple baffling in the hot gas stream, and a theory formulated which shows what factors combined to produce the problem.

SEVERE industrial vibration problems are plaguing the structural engineer with seemingly greater frequency. This appears to stem largely from two causes: (1) mechanical structures are becoming larger, thus becoming more vibrationally redundant, and (2) the energies involved, with their associated vibration-stimulating forces, are increasing. Accordingly, many problems which could at one time be ignored with safety cannot now be so easily forgotten. Vibration at resonance can make any mechanical structure, no matter how

strongly reinforced, appear flimsy and result in its destruction either by excessive dynamic stresses or fatigue failure.

From time to time new problems are encountered which are startling in their difference from those of the "routine" variety with regard to origin, to say nothing of severity. The vibration problem with which we are concerned is one of these. It resulted not from a change in basic structural design (hundreds of similar units are vibration-free), but primarily from the alteration of design dimensions and gas flow rate which brought "vibration-harmony" to otherwise independent parameters.

Description of Plant and Problem

The locale of the subject problem was the Etiwanda Steam Station of the Southern California Edison Company. Fig. 1 shows the appearance of the plant at the time the problem was being studied. The No. 2 generating unit which appears in the background was unfinished at the time. This controlled-circulation, radiant-reheat type boiler and its No. 1 mate, each rated at 920,000-lb of steam per hour, together are capable of operating their associated steam turbines to develop a total gross power output of 270 megawatts continuously.
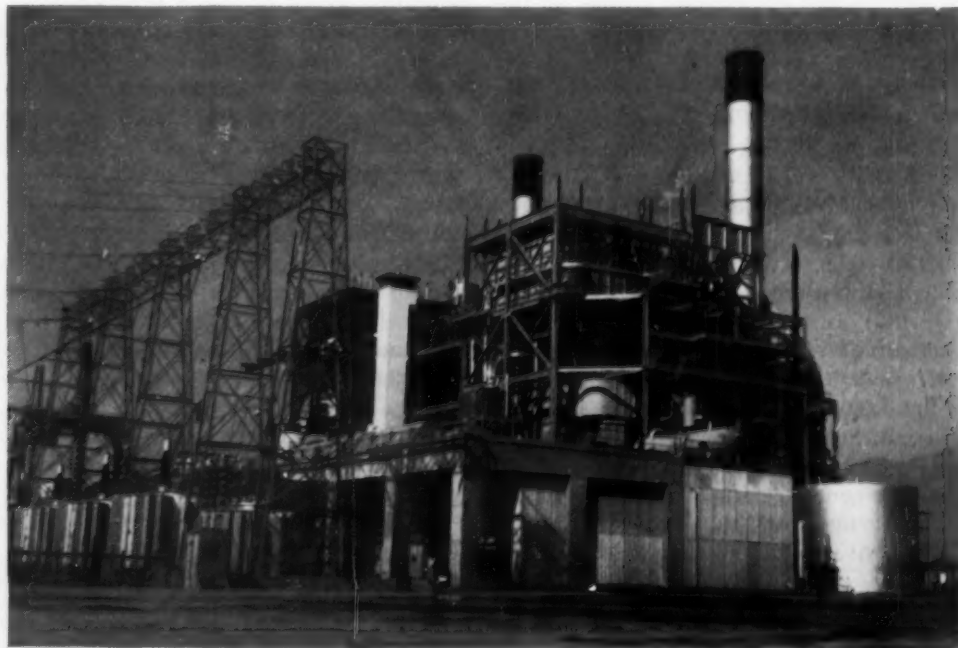

Fig. 1—Etiwanda Steam Station

The problem centered in the low-temperature super-heater-economizer section of Unit No. 1, and arose the first time the unit was operated at steam flows associated with turbine loads greater than approximately 86 megawatts when burning oil fuel and 105 megawatts when burning natural gas fuel. The severity of the vibration in its destructive effect on both metal and refractory material was greater than any other observed by the writer during several years of investigating similar industrial problems. The vibration was accompanied with intense sound which could easily be heard in the concrete enclosed control room some distance away. The seriousness of the vibration is indicated by Fig. 2 which shows the stringent "beefing-up" measures undertaken to strengthen the duct shell by the addition of large diagonal stiffeners completely around the ducting at several elevations.

Suspected Cause

It was fairly obvious that the energy source for the vibration was gas flow instability and that some form of acoustical resonance allowed large amplitude gas pulsation to develop. The essential elements giving rise to the phenomenon appeared to be: (1) a stream of flowing gas, (2) a duct channeling the flow and (3) obstacles to the flow caused principally by heat exchanger tubes oriented transversely to the flow direction.

Calculations based upon design temperatures showed that a full 45 cps standing-wave oscillation[1]† could exist oriented in the direction of the 37.9-ft dimension of the duct. This was very close to the frequency of the duct vibration as reported by Combustion Engineering field personnel.

It was postulated, therefore, that the energy source for the vibration was a standing wave transverse to the gas flow and parallel to the 37.9-ft duct dimension. However, the mechanism whereby energy of the gas stream maintained the oscillation did not become apparent until just prior to the complete solution of the problem.

Flow Instability

The matter at hand is a unique example of a vibration problem arising from flow instability. This problem has plagued aeronautical engineers and fluid flow specialists since the time of the Wright brothers, generally being referred to by the engineers as wing flutter. Large sums of money have been spent over a period of many years by the National Advisory Committee for Aeronautics in learning how to overcome the increased drag, vibration and airfoil effectiveness caused by such flow. Structural engineers have frequently been dismayed by the vibration of large structures caused by flow instability forces due to wind having the requisite meteorological characteristics, one example being the failure of the Tacoma Narrows vehicular suspension bridge.[2]

Class of Problem

The writer had previously encountered structural vibration problems such as this arising from wind.[3,4] However, they differed from the one at hand in an important way. For them, oscillation depended upon the frequency of instability-induced forces being synchronized with the natural vibrational frequency of the structure.

† Superscript numbers refer to bibliography at end of paper.

In the subject problem, however, the minute and randomly occurring instability forces arising from flow over parallel heat-exchanger tubes need an acoustically resonant chamber to synchronize and amplify them. The vibration then arises from the standing wave pressure variations acting directly upon the walls of the duct. In the Etiwanda problem, it was indeed fortunate that none of the natural vibration frequencies of the duct or exchanger tubes coincided with the standing wave frequency. Otherwise, it is probable that the structure would not have lasted long enough for a cure to be effected. The test measurements did, however, show that one of the buck-stays did have a natural frequency not far removed from the forcing frequency. As a result, only after complete removal of the pulsation did its vibration level (acceleration) drop abruptly to nearly
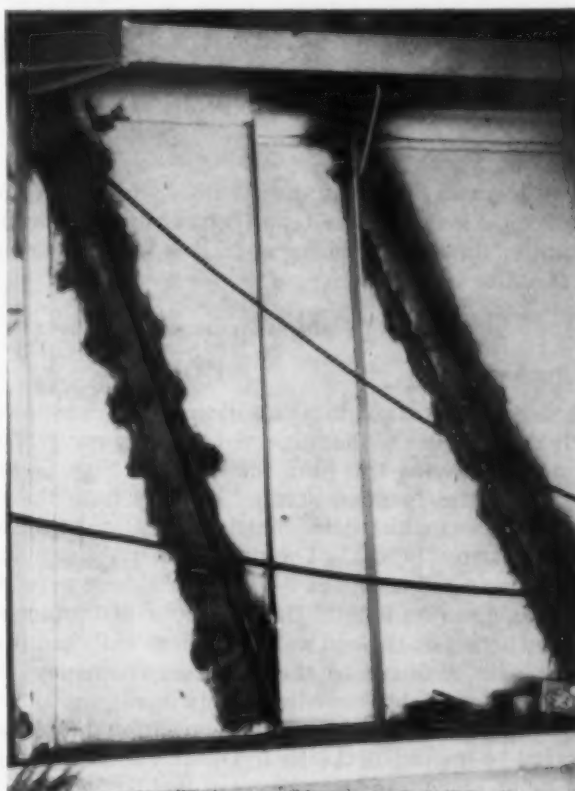
Fig. 2—Duct reinforcement

zero, whereas all other levels reduced in proportion to the strength of the pulsation.

Instrumentation and Acquisition of Data

To determine the extent and magnitude of the problem, three kinds of measurements were made: (1) vibration, (2) sound and (3) gas pulsation.

Vibration and sound levels and frequency analyses were acquired using General Radio level meters and frequency analyzers. Fig. 3 shows the distribution of sound and vibration test points. It indicates the test coverage of the problem and gives some idea of its overall magnitude.

Gas flow pulsation measurements were made with a view toward determining the presence and the orientation of standing waves. For this purpose a strain-gage type differential pressure transducer was employed. Fig.
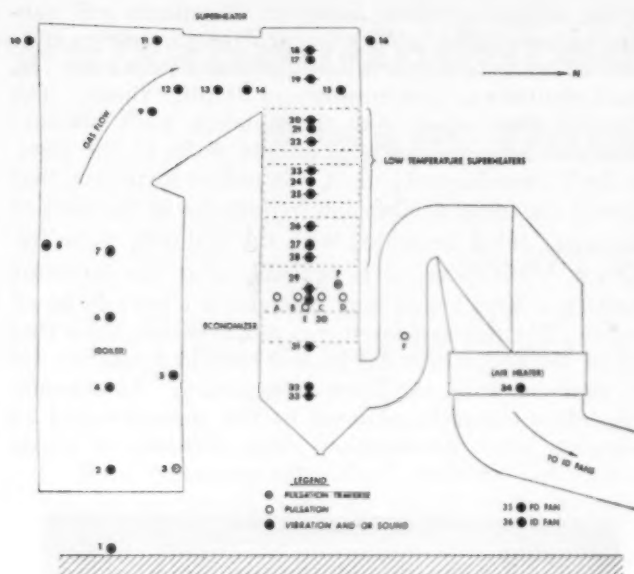
Fig. 3—Survey test points

4 shows how this device was used with a probe to explore the space between the low-temperature superheater and economizer tube banks during operation to locate acoustical standing waves.

Results of Field Measurements

GAS PULSATION

The measurements of duct pulsation conditions showed clearly the presence of the suspected standing wave. Two sets of data proving this form the bases for Figs. 5a and 5b. Notice the "postage stamp" samples from the oscillograph traces which determined the location of the associated plotted points. The maximum pulsation amplitudes measured at the end wall of the duct were ±3 psi. This gives an idea of the enormous instantaneous pressures acting on the end walls. If these walls had been mechanically resonant to the pulsation frequency, the result would probably have been disastrous.

Fig. 5c shows the variation of pulsation amplitude across the 14-ft width of the duct. Data for this curve were acquired by placing the transducer at test points A, B, C, and D (Fig. 3). The reduction in amplitude toward the walls is presumably due to wall friction. No other evidence was found for the existence of a standing wave parallel to the 14-ft duct dimension.
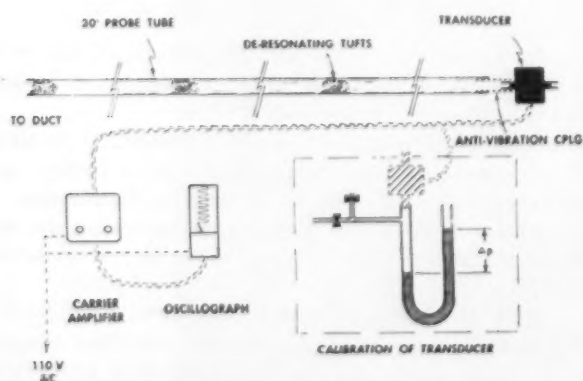
Fig. 4—Measurement of gas pulsation

No pulsation of significant magnitude was found either in the fuel burning region of the boiler or in the ducting to the induced-draft fans.

While Unit No. 1 was operating and "pulsating," a sound level traverse was made in Unit No. 2, the latter being, of course, cold and off the line. Here, another clear-cut example of a standing acoustical wave was found, also oriented parallel to the 37.9-ft duct dimension. This standing wave is superimposed in Fig. 5b. It will be noticed that this wave is $1\frac{1}{2}$ wave lengths long instead of 1, even though it has the same frequency as the wave in Unit No. 1. This results from the difference in temperature between "hot" gas in Unit No. 1 and the "cold" gas (air) in Unit No. 2. The difference in sound propagation velocities for these gases accounts exactly for this difference in the number or wave lengths. The general result clearly illustrates the ease with which parallel walls can cause standing waves to form. The standing wave in Unit No. 2 completely disappeared when Unit No. 1 was taken out of oscillation (by reducing flow rate), thus showing the smallness of the amount of energy required to set up a standing wave, providing resonance exists. It might be mentioned that a fairly intense standing wave pattern was found to exist in the
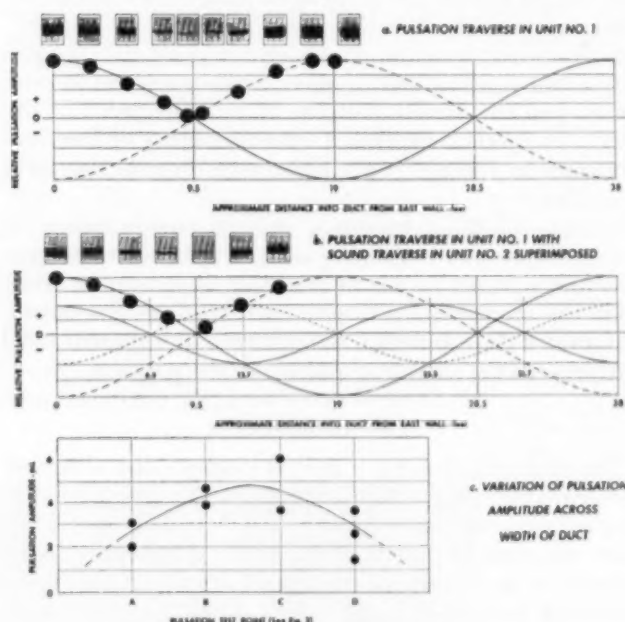
Fig. 5—Gas pulsation waves

open space between the units because of this same parallel-wall effect. Nodes and loops of the wave were easily located by means of a sound level meter on the catwalks running between the units. The intensity from "peak" to "trough" of the wave varied as much as 20 decibels.

VIBRATION

The general vibration survey made in accordance with Fig. 3 showed the highest levels to be occurring on the low-temperature superheater-economizer duct. Accordingly, test points on the duct were selected as indicators. The vibration levels (acceleration) of these points (buckstay center points) are plotted in Fig. 6, curve (a). It will be noticed that the highest intensity is centered about point 29 which is adjacent to the space between

the low-temperature superheater and economizer sections. Curves (b), (c) and (d) of this figure show the vibration levels which remained after the problem had been solved, for different gross loadings.

SOUND

As with vibration, the general survey (Fig. 3) disclosed that the most intense sound levels occurred immediately adjacent to the low-temperature superheater and economizer areas. Therefore, test stations here were also chosen as indicators. The original levels are shown in Fig. 7, curve (a). As with vibration, sound levels of highest intensity occurred adjacent to the space between the low-temperature superheater and economizer sections. Curves (b), (c) and (d) show the levels remaining after the problem had been solved. It should be mentioned that the sound level 6 ft from the inspection port (P of Fig. 3) was 126 decibels with the port door opened. One hundred and thirty decibels is usually given as the level at which the human ear begins literally to "come apart." Working for protracted periods with sound levels of 115 decibels or greater is considered to be both physiologically and psychologically harmful, especially if the sound energy is all concentrated at one frequency as in the subject case.

The Projected Remedy

After experimentally verifying that the source of trouble lay in the existence of a standing pulsation wave,

VIBRATION LEVEL — ACCELERATION IN INCHES PER SEC²

Fig. 6—Vibration levels, Unit No. 1
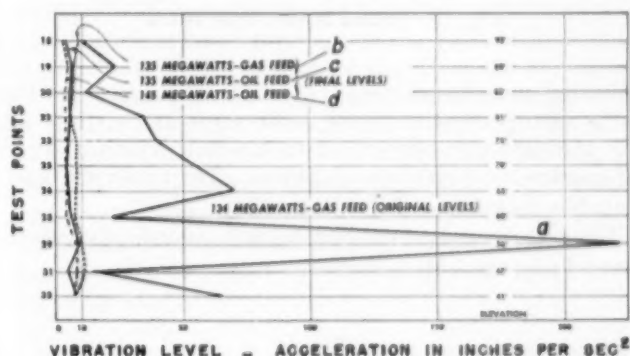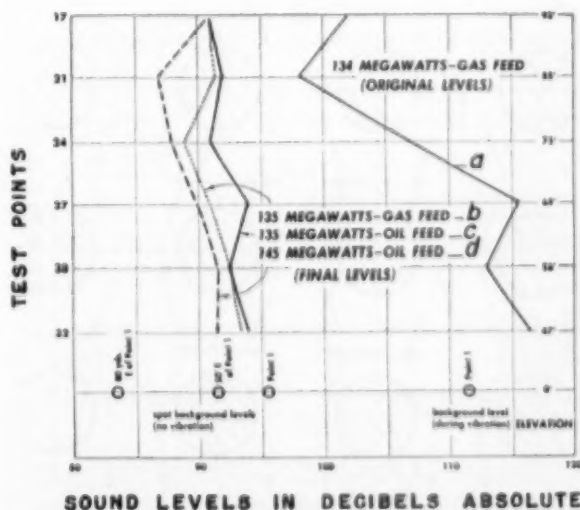
SOUND LEVELS IN DECIBELS ABSOLUTE
Fig. 7—Sound Levels, Unit No. 1

two possible solutions came to mind. One of these, a change in operation to keep gas flow velocity out of the critical range, was immediately discarded as being impractical. The other was to insert transverse baffles, much like straightening vanes, at the points of maximum gas-particle displacement in the standing wave. Since the wave was perpendicular to the flow direction, the baffles would offer no restriction to the flow.

In a standing wave, the locations of maximum particle displacement (acoustical current) are 90 deg out of phase with the locations of maximum gas pressure (acoustical voltage). Therefore, referring to Fig. 5, it is apparent
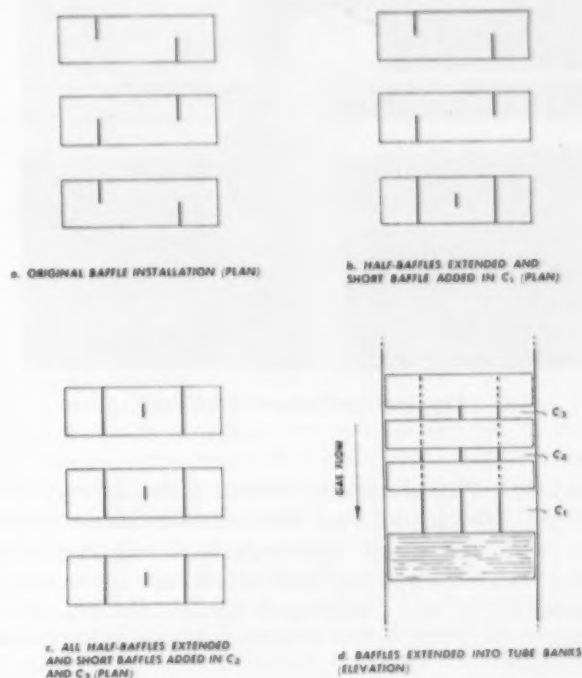
Fig. 8—Placement of de-resonating baffles

that to be most effective, the baffles should be located one-quarter of the way in from each end wall.

Pulsation in Tube Banks

It was originally thought that "de-resonating" the spaces between the banks of coils would answer the problem because of the high acoustical resistance that the banks would have to a pulsation wave of 40–50 cps frequency. Furthermore, the variation of temperature as the gas passed through each bank was considered, in itself, to be enough of a deterrent to resonance. It was even believed that half-baffles arranged as shown in Fig. 8a would be enough to completely cure the problem. However, at that time the source of the energy for the oscillation was not understood. Fig. 9 shows the installation of one of these baffles in the space between the low-temperature superheater and economizer sections. Note the access port through which the baffles were passed in pieces (P of Fig. 3). All welding took place inside the duct.

Results

After the half-baffles had resulted in a great improvement in vibration, sound and pulsation levels, they were extended to completely span the duct as shown in Figs.

Fig. 9—Installation of baffles

VIBRATION LEVEL — ACCELERATION IN INCHES PER SEC²

Fig. 10—Vibration levels, Unit No. 2

SOUND LEVELS IN DECIBELS ABSOLUTE

Fig. 11—Sound levels, Unit No. 2

8b and 8c. This eliminated all but a small "residual" pulsation. The baffles were then extended into the tube banks with the result that pulsation and attendant vibration were completely eliminated even for overload conditions (Fig. 8d). With each change, the gross load the unit could carry before vibration appeared, increased appreciably.

The results of the incremental additions to the original set of baffles are presented in Table 1. Figs. 6 and 7

TABLE 1—EFFECT OF ACOUSTICAL DE-RESONATING BAFFLES

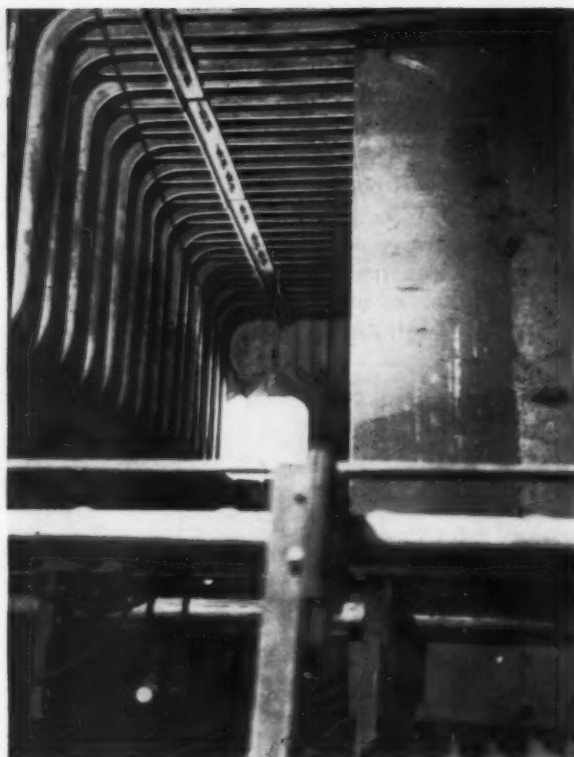| Extent of Baffling (Refer to Fig. 8)	Max. Gross Load Without —Pulsation (Megawatts)— Gas Feed	Oil Feed	Reduction of Pulsation Amplitude from Original Level, %
No baffling	105	86	. . .
a	119	90	85
b (and c)	132	95	99
d	145+	145+	100

show the "before and after" sound and vibration levels. Those remaining are, if anything, lower than those one would expect in a plant of this type, as constituting ambient conditions.

It should be pointed out that the short baffles indicated in Fig. 8, located at the center of the duct, were put there for the purpose of inhibiting the formation of standing waves in the space between the parallel quarterway baffles.

Addition of Baffling to Second Unit

Unit No. 2 was undergoing completion while the solution to the problem was being worked out for Unit No. 1. There was insufficient time to incorporate the complete baffle arrangement in the second unit before putting it into operation. However, the interbank baffling was installed. Subsequently, at high loading, some residu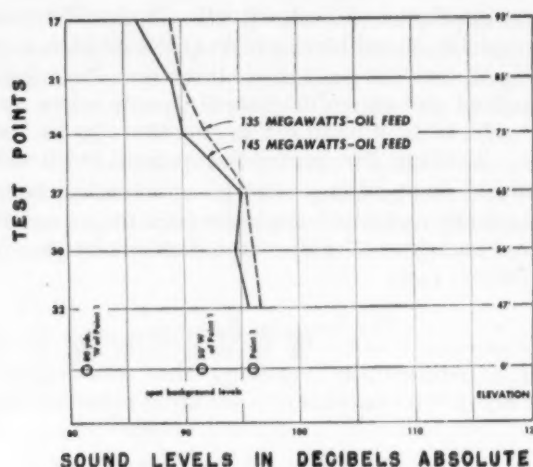al pulsation and vibration was reported. Completion of the baffle arrangement to make it the same as that in Unit No. 1 completely eliminated that which remained even for gas flows at overload conditions. The final results for Unit No. 2 appear in Figs. 10 and 11.

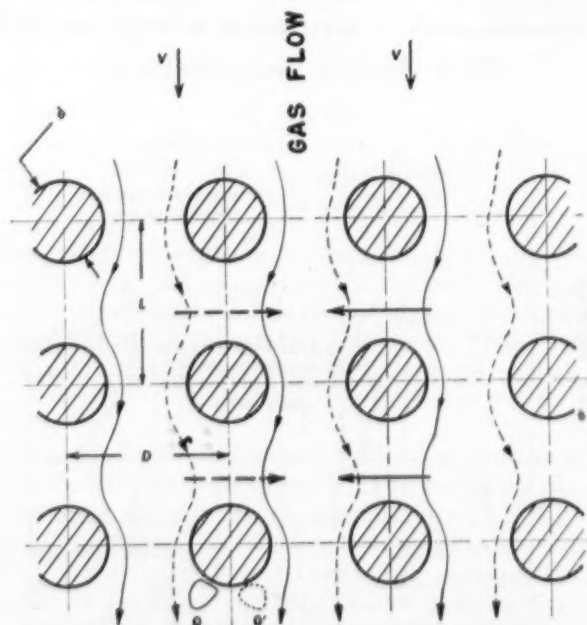The effectiveness of the baffling was accordingly proved beyond any shadow of doubt.

Fig. 12—Formation of instability pulses

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Theory

All observed phenomena (vibrational, acoustical and pulsative flow) can be readily explained by assuming that the downward flowing gas interacts with the low-temperature superheater tubes to produce oscillating transverse flow pulses. These pulses are coupled with the resonant chambers which, under certain conditions, allow for an acoustical standing wave to be developed within a certain range of gas flow velocity.

VON KÁRMÁN EFFECT

The generation of the lateral oscillatory pulses is of the same type which gives rise to the phenomenon frequently referred to in the literature as the "von Kármán Trail." This is the fluid-flow phenomenon which sometimes causes the destruction of smokestacks, suspension bridges and other similar structures by wind.[5]

This unstable flow phenomenon as applied to the matter at hand is illustrated in Fig. 12 which shows the hypothesized instantaneous gas flow path (streamlines) at different times during a pulse cycle as the gas passes downward through a bank of horizontal cylinders arranged on square centers. The tubes of the low-temperature superheater at the Etiwanda station present this same configuration. The production of the laterally directed pulses is due to the obstacle effect caused by the cylinders (heat exchanger tubes), as a result of which a migratory low-pressure region is formed downwind of each cylinder (O and O' of Fig. 12). The gas, in attempting to equalize this pressure, overshoots (i.e., overcompensates) which, in effect, moves O to O'. Subsequently, overcompensation then occurs by the gas stream from the opposite side. The oscillatory process is thus continued providing the gas flow rate is such that the period of the oscillation is equal to the time required for the gas to pass between alternate rows of tubes. This periodic motion results in a general pulsing shift of the gas stream as a whole transverse to the flow direction.

The relationship between pulse frequency and the gas flow velocity is linked to the cylinder diameter in the following way:[6,7]
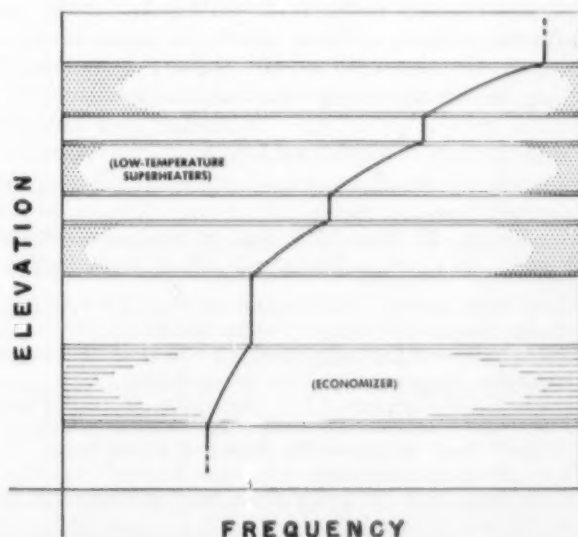
$$f = k \frac{v}{d} \quad (1)$$
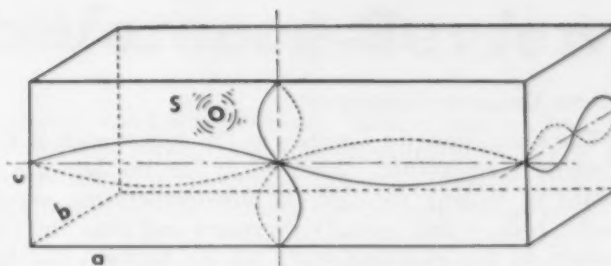
Fig. 13—Variation of instability-pulse frequency

Fig. 14—Standing waves in resonant chamber

where the terms referred to are:

f = Frequency
k = Proportionality constant
v = Incident flow velocity
d = Cylinder diameter

The acoustical coupling between the laterally adjacent cylinders is sufficiently tight for causing the pulses to be forced into the same phase relationship with each other.

It is certain that f is somewhat affected by temperature because of the density change it causes but this factor can probably be safely ignored in relation to the others. v is, of course, linearly affected by temperature. Furthermore, the lateral spacing D will affect f, while the relationship of D to L (Fig. 12) may make it impossible to form pulses in certain frequency ranges, regardless of the flow velocity. Calculations for velocities corresponding to frequencies of 40 to 50 cps give values of the same general magnitude as those actually present at the Etiwanda plant.

The above can be summarized in the form of a curve relating f with distance through the low-temperature superheater section (i.e., as temperature decreases) as shown in Fig. 13. If, now, at any specific elevation we have coupled an acoustically resonant chamber "tuned" approximately to the instability-generated pulse frequency, a standing wave condition can be set up with an intensity dependent upon the strength of the excitation and the dissipative characteristics of the chamber.

RESONANT CHAMBERS

Fig. 14 shows a rectangular box having dimensions a, b, and c. S is a source of sound of variable frequency f. If the period of the sound frequency, $(1/f)$, is adjusted to have a value equal to or a submultiple of that required for a sound pulse to propagate from one wall to the opposite wall and return, a standing wave can be set up which may attain great amplitude by the addition of a small amount of energy from S during each cycle. Fig. 14 shows such standing waves as would be set up along the three axes of the chamber. Note that these are particle displacement or volume-current waves which are 90 deg out of phase with their associated standing pressure waves. The fundamental frequencies for generation of planar standing waves (full-wave) between each set of walls are as follows:

$$f_a = \frac{C}{a} \quad (2)$$

$$f_b = \frac{C}{b} \quad (3)$$

$$f_c = \frac{C}{c} \qquad (4)$$

Sound Velocity Variation

The sound velocity C varies as the square root of the absolute temperature. Accordingly, as the hot gas is cooled in passing through the low-temperature superheater coils, sound velocity decreases and thus the frequency of any standing wave set up between parallel walls will decrease in the direction of flow. Fig. 15 is a graph of this variation with the curve of Fig. 13 superimposed. The intersection of the curves determines the elevation at which pulsation can most easily occur.

Generation of Standing Wave

If, as is the case in the subject problem, a heat exchanger is interspersed with resonant chambers and the temperature, flow rate and dimensional factors are correct, standing waves can be readily produced in such chambers, the necessary energy for which being gen-
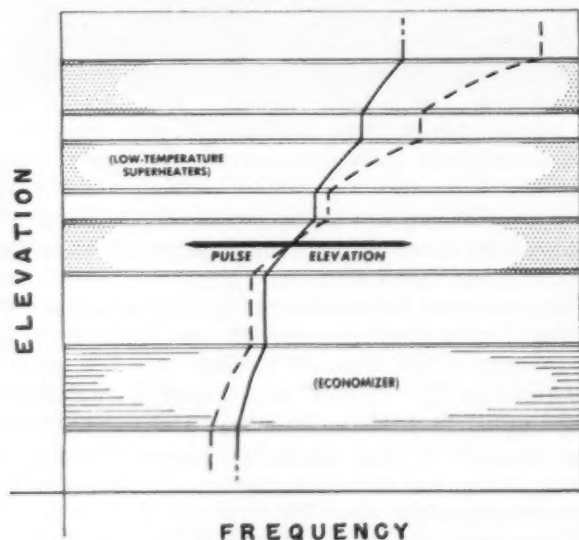

Fig. 15—Variation of duct-resonance frequency

erated by the flow instability phenomenon described. It should be noticed that orientation of the low-temperature superheater tubes is proper to excite standing wave oscillation in the direction of the 37.9-ft dimension of the Etiwanda ducting. In this mode the maximum instantaneous pressure variation occurs at the centers of the 37.9-ft walls and is more or less uniformly distributed over the 14-ft wide end walls.

From the foregoing, it is apparent that a number of physical factors enter the picture in determining whether or not pulsation-produced vibration such as that encountered at the Etiwanda plant can be produced. These factors may be listed as follows:

1. Temperature
2. Flow rate
3. Duct dimensions
4. Tube diameter
5. Tube orientation with respect to ducting
6. Tube spacing—both vertical and horizontal
7. Location of resonant "chambers" in ducting.

Summary

The Etiwanda noise and vibration problem was shown by direct experimental measurement to result from the presence of a standing pulsation wave in the gas stream. This source of vibration stimulating energy was originally localized in the space between the low-temperature superheater and economizer sections. A complete vibration and acoustical survey of the entire furnace structure revealed no other source of pulsative energy of this type. The installation of simple baffling to prevent formation of standing waves proved extremely effective in eliminating the gas pulsation, together with its attendant sound and vibration.

A theory has been formulated which explains the generation of the pulsation and accounts for the observed phenomenon and all its anomalies. The theory is based upon unstable flow, produced by cylindrical obstacles in a stream of gas, coupled with acoustically resonant chambers. The condition giving rise to pulsation with its associated vibration and sound depends directly upon variables such as flow velocity, temperature, duct dimensioning, exchanger design, etc. Changing one or more of these variables can have a large effect on the probability of pulsation generation. The theory explains why vibration trouble of the Etiwanda type may show up even though the offending unit may superficially appear to be identical in design to others which have never given any trouble.

It would seem that demands for higher capacity steam plants are resulting in furnace designs and operating conditions which are more and more likely to result in severe gas pulsation with its associated vibration and noise. Although baffles could be installed as a form of insurance against this contingency, such a procedure is believed not at all necessary providing care is exercised to keep flow velocities and dimension ratios away from mutually critical values. In any event, the design should be carefully watched during the early stages. Otherwise, pulsation might appear during operation of the constructed unit which cannot be handled by the relatively inexpensive application of non-cooled de-resonating baffles.

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American Power Conference Review

AT THE sixteenth annual meeting of the American Power Conference held at the Sherman Hotel in Chicago on March 24–26, one of the features was participation in Light's Diamond Jubilee Celebration marking the seventy-fifth anniversary of the invention of the electric light by Thomas A. Edison. With a registration approaching 2500, attendance at technical sessions and special events reached record heights.

Opening the meeting, **Lenox R. Lohr** of the Chicago Museum of Science and Industry paid tribute to the pioneer work of Thomas A. Edison. He noted that the invention of the electric light came just 75 years after Watt's steam engine was put into practical use in this country. **Vice Admiral Harold G. Bowen** of the Thomas Alva Edison Foundation, Inc., continued in a historical vein in a paper entitled "The Beginnings of the Light and Power Industry." This included a brief account of experimental work at the Edison laboratories in Menlo Park, N. J., and the early problems of manufacturing.

Addressing Light's Diamond Jubilee Dinner, **C. H. Moses,** president of Arkansas Power and Light Co., commented optimistically on prospects for the next 25 years. He anticipated a doubling of national income within that period and an increase in the working populace from 62,000,000 to 85,000,000. On the other hand, Mr. Moses raised questions concerning the future role of government in business, noting that some rights surrendered during World War II have never been restored to individuals. He declared that business has never faced a greater challenge, nor has it had greater opportunities and responsibilities than at the present. By way of example he told of the activities of his own company in promoting citizenship responsibility in its state.

William A. Lewis of the graduate school at Illinois Institute of Technology and **Jesse E. Hobson** of Stanford Research Institute contended that the future of the electric power industry is threatened because it is neglecting the basic research needed to keep any industry in a competitive position. In a paper entitled "Research and the Electric Power Industry" they stated that there has been too much dependence upon the research efforts of a few electrical manufacturers. Very little is known concerning the amount of research now being conducted by the utilities, and one of the first steps would be to have a team of research experts make personal visits to selected companies to obtain information which would serve as a basis for the intelligent evaluation of the industry's present status. The authors proposed that an industry-wide association with affiliated laboratories be formed with an annual budget of $7,000,000.

At the opening luncheon **Walter H. Sammis,** president of Ohio Edison Co. and Edison Electric Institute, stated that the electric light and power industry is basically an engineering operation and because of its technical nature always will be. Its financing, sales activities, public relations, accounting and legal phases of the business are all built upon engineering characteristics. Growth of the industry has been linked with engineering accomplishments and depends upon top quality leadership.

In another luncheon address, **J. K. Kuykendall,** chairman of the Federal Power Commission, said that only 21 per cent of the nation's potential hydroelectric power capacity has been developed. Half of this has been accomplished through privately financed projects and the remainder through public projects. Present policy is for the Federal Government to undertake construction of only those water resource development projects or parts of projects which cannot be built by local interests or which have a national significance. Other projects are to be left to non-federal public or private interests.

Douglas McKay, Secretary of the Interior, speaking at the All Engineers Dinner, revealed that an agreement has just about been reached between the Federal Power Commission, the Department of the Army and the Department of the Interior with respect to a uniform and equitable method of cost allocation for Department projects. He added that power must bear its full share of costs, and these must be returned to the Federal Treasury, with interest, within a period of fifty years.

Speaker at the final luncheon was **A. C. Monteith** of Westinghouse Electric Corp., whose subject was "Future Energy Sources." If the present rate of increased use of energy is continued, some new source will have to be found, and with current developments that source apparently is going to be the atom. He predicted that atomic powered generation will find an orderly application on utility systems and that present equipment will not become obsolete except as it becomes economically advisable to retire it.

Central Station Design

In a paper entitled "Economy of Large Generating Units" **H. P. Seelye** and **W. W. Brown** of The Detroit Edison Co. explained some of the results of an economic study which led to the decision to install two units, each having a maximum rated capability of 260 mw, in a new plant at River Rouge, Mich. Cost comparisons were made for 260-mw cross-compound double- and single-flow machines and a tandem-compound triple-flow machine. On the basis of an average 56 per cent plant factor for a 35-year life, the appreciably better heat rate and resulting fuel savings of the cross-compound double-flow unit offset its higher investment cost.

Studies were made for generating units of 156, 175, 200 and 260 mw, with the final choice being between the two largest sizes. Total plant cost per kilowatt for two units was found to be $172.50 for the 200-mw units as against $146.92 for the 260-mw units. Incremental cost for 120 mw in the comparison was found to be $61.67. This relatively low figure is attributed to the somewhat lower cost per kilowatt of the equipment itself and by such items as site, site development, building, coal handling, instrumentation, design and engineering, the cost of which is little affected by differences in unit size. Other studies were made to select steam conditions, to determine initial investment and to compare annual costs.

The authors concluded that there are appreciable advantages and no serious disadvantages in adopting a size of generating unit which is relatively so large in comparison with the system load as the one which has been ordered for the Detroit Edison system.

C. E. Blee and H. J. Petersen of the Tennessee Valley Authority presented a paper entitled "The Gallatin Steam Plant of the Tennessee Valley Authority" in which they described some of the more important features of that plant and discussed reasons for their adoption. Located on the Cumberland River near Nashville, Tenn., the Gallatin plant is scheduled to start operations late in 1955 and will initially include two units, have a capability of 250 mw each and operating at 2000 psig, 1050 F, with reheat to 1050 F.

The unit system of one boiler per turbine is employed, with partial outdoor construction which includes dust collectors, induced-draft fans and duct work. The turbine-generators are single-shaft, tandem-compound triple-flow units. The 250-mw rating was chosen because manufacturers with their design experience on 200-mw units felt no hesitancy in going to the higher rating and because of the advantages of less operating labor and less building space per kw. In terms of system capacity, these units are of smaller proportionate size than the 60-mw Watts Bar units were when they were installed in 1942.

The steam generating units are twin-furnace, controlled-circulation, tangentially fired units. The entire reheater is installed in one furnace and the finishing-off section of the superheater in the other, permitting temperature control separately in each furnace. This design of separated furnaces also has the structural advantage that it is possible to install a center column between them, thereby decreasing the size of the supporting girder and other structural members.

Large Steam Generating Units

E. M. Powell of Combustion Engineering, Inc., presented a paper entitled "Performance of New Controlled Circulation Boilers" in which he pointed out the controlled circulation principle provides positive circulation on start-up, acting analogously to a turbine turning gear, and makes possible uniform tube temperatures because circulation is controlled in exact proportion to calculated heat distribution. He told of tests conducted at the Kearny Station of Public Service Electric and Gas Co. which have shown that the total water circulated through the unit is held constant over the entire range, starting with a cold unit. Also the variation of flow between one tube and another in a given circuit will not vary more than plus or minus four per cent over the entire range of output.

The design of drum internals is an important part of these units. Mr. Powell described how the steam and water mixture from the water walls enters at the top of the drum and sweeps the drum shell in its path to the bottom. The mixture then enters the turbo-separators in which centrifugal force is created by vanes giving the mixture a spinning action as it passes vertically through the separators. An effort has been made to provide rapid heating of all portions of the drum shell to facilitate starting-up at higher rates and to minimize temperature differences within the drum. In a test conducted at the Etiwanda Station of Southern California Edison Co. the unit was heated up at the rate of 200 deg F per hour, or about double the conventional rate, and load was placed on the generator within $3\frac{1}{2}$ hr of initial firing.

With regard to heat absorption by evaporating surfaces, Mr. Powell pointed out that the small thin tubes which are possible with controlled circulation have less temperature stress at a heat input of 200,000 Btu per sq ft per hr than a 3-in. tube has at 100,000 Btu input. He explained the advantages of tying two separated furnaces together with a common circulating system, as is being done in the controlled circulation unit for the Cromby Station of Philadelphia Electric Co. and for several other installations. This made center supporting columns possible, simplified the structural problems, and permitted access to all furnace walls.

A second paper at the same session was presented by George W. Kessler of The Babcock & Wilcox Co. under the title "Cyclone Furnace Boilers." After describing the principles of the cyclone furnace and establishing the differences between this method and pulverized coal firing, he outlined some of the problems encountered in the development since the first commercial installation began operation in 1944. In the intervening years changes have been made in the arrangements of tubes, stud plate, the cone section between the burner and barrel section, the inlet connection of the burner, and the slope of the cyclone. Mr. Kessler explained the solutions which led to these changes.

With respect to suitability of coals for cyclone furnaces, it was estimated that 70 per cent of the 512,000,000 tons of bituminous and lignitic coals mined in 1950 in this country could have been burned. It was stated that this type of firing is adapted to burning western sub-bituminous and lignitic coals. The author listed twelve advantages claimed for cyclone furnaces, many of them relating to operating conditions and air pollution problems. He pointed out that considerable thought is now being given to the use of cyclone furnaces for oil and gas firing.

Fly Ash Disposal

In a paper entitled "The Present and Future Status of the Fly Ash Disposal Problem" C. M. Weinheimer of The Detroit Edison Co. presented figures showing fly ash production. In 1943, 39,000,000 tons of coal were pulverized and burned, from which approximately 2,800,000 tons of fly ash was produced. In the decade ending in 1953, coal consumption by the utility industry increased by 50 per cent, while the fly ash production index increased from 100 in 1943 to 242 in 1953. The amount of fly ash collected in 1953 is estimated to be 6,100,000 tons, and there is the possibility that it may increase to 16,800,000 tons in 1963.

Mr. Weinheimer reported that work is being conducted with ASTM on specifications for fly ash as an admixture in portland cement concrete, as a pozzolanic material, and as a blending material for cement. Efforts are being made to establish non-prejudicial freight rates which would extend the area in which fly ash can be economically shipped. Satisfactory markets for fly ash disposal would have these characteristics: (1) provide revenue or be disposed with little or no cost to the producer, (2) consume a large tonnage, (3) be non-seasonal in character, (4) contribute some beneficial results to the economy of the country.

Supercritical Pressure Cycles

Professor Jerome Bartels of the Polytechnic Institute of Brooklyn, in a paper entitled "Supercritical Pressure Steam Power Cycles," characterized the supercritical pressure region as one in which steam generation is a monophase process wherein water gradually expands to steam without any distinct bubble formation or any abrupt change of phase. Limiting himself to thermodynamic considerations, the author presented some of the underlying reasons for the better thermal performance of supercritical pressure cycles, showed the effect of throttle pressure and temperature upon the efficiency of non-extraction cycles for values up to 8000 psia, and gave some idea of attainable heat rates.

In analyzing a 1200-F, 6800-psia cycle with double reheat to 1200 F and eight stages of feedwater heating, Prof. Bartels proposed an interesting innovation at the exhaust end of the cycle. Under these conditions the exhaust has an enthalpy about 75 Btu above the saturation value. Instead of discarding this energy to the circulating water, a desuperheating zone is incorporated in the neck of the condenser to serve in feedwater heating. Assuming a regenerator effectiveness of 77 per cent, omission of this equipment would cause the turbine room heat rate to increase by 47 Btu per kwhr.

Nuclear Reactors

Dean Donald H. Loughbridge of Northwestern Technological Institute presented a paper entitled "The Economic Aspects of Various Types of Nuclear Reactors." He stated that many capable engineers making government studies have been irked by the past tendency to hesitate in approving the construction of a nuclear power plant until paper studies could show a good expectation of generating power at competitive rates. With regard to the decision of the Atomic Energy Commission to build a prototype plant without the expectation of generating competitive power, Dean Loughbridge felt that this was at least partly motivated by strategic international factors related to the peaceful use of nuclear power.

Although dual-purpose reactors were seriously considered in the first AEC study contracts with industrial teams, advances during the past three years in meeting military requirements for plutonium have been so great that efforts have been abandoned to justify nuclear power economics by sale of plutonium. Even if the military market should remain constant or increase, it was stated that plutonium and power affect a reactor design in such different ways that it would be very difficult to distribute the costs properly to the products and arrive at an intelligent basis for cost.

In a paper entitled "Problems of Nuclear Power Plant Operation," **R. L. Doan** of the Atomic Energy Division of Phillips Petroleum Co., Idaho Falls, Idaho stated that the problems that are rather special to nuclear reactor installations are those that have to do with the physical characteristics of the nuclear reaction, the very intense and penetrating radioactive radiations associated with it and the great importance to our national security of the fissionable material used as reactor fuel.

With regard to safety, all reactors now in operation in this country as well as those in the advanced development stage have been the subject of hazards survey reports. Reactor operational safety depends upon core geometry, excess reactivity, reliability of control system and coolant, and adequacy of instrumentation.

Nuclear power reactors of the future are expected to operate in regions of high specific power, which means high neutron fluxes. Radiation damage becomes a more severe problem as neutron flux level increases, as does the matter of heat transfer. In a nuclear reactor it is relatively easy to reach power densities many times greater than those found in internal combustion engines or even rockets. Also, the problem of neutron detection and control instrumentation is more difficult at high flux operation than at low.

Two major operating cost items when enriched fuel is used are the fabrication of the core and the recovery of fissionable material from spent cores. If economies are to be realized, it will be necessary to simplify core structure, to arrange the core geometry for maximum fuel burnup, and to find simpler chemical processing methods.

An interesting comparison of coal-fired steam plants with water-cooled reactor systems was made by **Alfred Amorosi** of Argonne National Laboratory in a paper entitled "Technology of High-Pressure Water Reactor Systems." By contrast to an allowable leakage of one per cent in a steam plant, or 25,000 lb of water per hour for a 300,000-kw installation, the maximum rate in an equivalent nuclear plant is 100 lb per hour. With regard to corrosion, the permissible rate for radioactive systems is expressed as a few pounds per year, as compared to hundreds of pounds in a conventional steam plant. Additives in the form of sulfites and phosphates commonly used in central stations cannot be permitted in nuclear plants because of the radioactivity that would be induced in them.

In concluding Mr. Amorosi stated that it may not always be necessary to use expensive materials and equipment in a reactor system. In the case of the radioactivity problem associated with transported radioactive corrosion products, it is difficult to predict where these products will go and how difficult it will be to cope with them. Corrosion-resistant materials have been chosen to minimize these problems. As experience is gained it may be possible to use cheaper materials of less corrosion resistance.

Turbine-Generators

There were three papers which traced the evolution of central-station steam turbine-generators and offered some forecasts of future developments. The three papers, as might be expected from their titles, covered very similar subject matter, so that this account represents a selection of highlights from each of them.

Leading off the session was a paper entitled "Steam Turbine Developments" by **C. C. Franck** of Westinghouse Electric Corp. In designing for operation with high-temperature steam, selection and availability of materials are foremost considerations. Their properties and behavior under high temperature must be

known, and consideration must be given to the practicality of the materials for manufacture and metallurgical testing. The designer must take into account the pressure stress caused by the direct forces exerted on the walls and the thermal stresses caused by temperature variations. To carry this out, all parts should be free to expand or contract without changing their basic relative positions, and temperature gradients should be reduced as uniformly as is practical.

With reference to turbines operating above the critical pressure, Mr. Franck proposed two design approaches. In both cases the turbine element taking the super-pressure steam represents an additional independent casing. This element might have its own thrust bearing and be connected to the main shaft through a flexible coupling. The first design, designated as conventional, would be for steam conditions of 5000 psig, 1150 F, with two stages of reheat to 1100 F and 1050 F, respectively. The inner casing would consist of a cylindrical forging into which the rotor and prefitted stationary elements are inserted as a single assembly, thus eliminating the conventional horizontal joint. This unit would utilize available materials at stress levels which would result in reasonable life expectancy of rotating and stationary parts.

The second proposed type of turbine for supercritical pressures would be designed for temperatures in excess of 1150 F. Materials would be utilized at stress levels which would result in relatively short life expectancy, so that careful economic studies would have to be made to justify their expendability. A machine was proposed for 5000 psig, 1250 F with reheat to 1100 F and 1050 F. The physical size of the machine is limited by reducing the energy drop by operating at an elevated exhaust pressure. The steam exhausted from the expendable high-pressure section would be readmitted, following reheating, to what amounts to a conventional turbine.

"Design Trends in Present-Day Steam Turbines" was the title of a paper by **C. D. Wilson** and **E. P. Hansen** of Allis-Chalmers Mfg. Co. In essence, the trend is toward the building of more compact turbine-generator units of larger capability which are designed to operate with improved performance. The authors showed illustrations of 50-mw reheat turbines and noted that the overall length of a single-cylinder machine is about 87 per cent of that of a tandem compound. This saving in length is obtained at a slight sacrifice in performance due to smaller blade area in the exhaust. By using a fully supercharged, hydrogen-cooled generator, the length is reduced to 67 per cent of a tandem-compound reheat unit and is even shorter than a 22-mw non-reheat Preferred Standard machine. The authors also made comparisons of several variations in design for 150-mw machines.

Referring to manufacturing and inspection processes, Messrs. Wilson and Hansen observed that forgings are replacing castings in many highly stressed parts such as valve manifolds and turbine casings. Ultrasonic procedures are used together with radiography in the observation of discontinuities or other defects in stressed parts. An unusual device used for radiographic inspection of steel sections up to two feet thick is a 24-mv

Betatron which reduces required exposure times to minutes instead of hours.

The third paper was by **R. S. Neblett** of the General Electric Co., whose topic was "The Steam Turbine of Tomorrow." He traced his company's efforts in making investigations of turbine-wheel and turbine-bucket breakage about 35 years ago, in preparing and extending steam tables during the 1920's, in developing tests for creep at high temperatures, in studying the aerodynamic performance of turbines, and in determining critical speeds of multiple spans of turbine-generator shafts. In connection with the last, IBM punch-card calculation machines and more recently an IBM digital-computer calculating machine may be used to solve the many simultaneous equations that are involved.

Much more attention is expected to be given in the future to the reduction of exhaust losses. It is necessary to design, calculate and test the lower stages on the basis of three-dimensional flow, and to this end a laboratory is now being constructed wherein investigations can be made of the exhaust stages of full-size 3600 rpm machines. Considering the present state of nuclear power generation in which typical steam conditions are on the order of 400 psig, 750 F, the new laboratory can perform a useful service in studying the properties of wheel and bucket combinations in the low-pressure, low-temperature end of the cycle.

At the other extreme, Mr. Neblett indicated that supercritical steam pressures are only suitable for large-capacity turbines. The net heat rate of a 100-mw unit cannot realize further reductions for initial pressures higher than 2500 to 3000 psig because the reduction in initial volume flow causes a loss in internal turbine efficiency which offsets the theoretical gain available from higher pressures. On a 200-mw unit this reduction in internal efficiency is smaller, so that there is an improvement in heat rate for higher pressures.

Water Treatment

The highly developed science of water treatment for both power boilers and cooling water cycles has traditionally been accorded considerable attention at the American Power Conference. This year's meeting fortunately was no exception. Four major sessions were scheduled on the general subject of water technology: (1) a two-paper program on feedwater and high-temperature process waters sponsored by the Joint Research Committee on Boiler Feedwater Studies; (2) a symposium on demineralization; (3) a meeting on water treatment problems and advances required by nuclear power and high-pressure boiler developments; (4) a session on water softening and silica removal without demineralizing plus a report on hydrazine.

The first of these four sessions featured two papers, one by **J. M. Decker**, senior research engineer, and **J. C. Marsh**, technical engineer, of Detroit Edison Company on the general evaluation of possible ferrous metal losses produced by alkaline compounds employed for controlling corrosion-erosion in boiler feedwater systems and a second presentation by **Paul L. Geiringer** and **Floyd Hasselriis** of American Hydrotherm Corp. on high tem-

perature water for process heating combined with power production.

Messrs. Decker and Marsh based their paper on what they felt to be a very definite research need occasioned by the widespread interest in pH control with ammonia and with amines to inhibit corrosion in steam water cycles of central power stations. The gains affected by increasing feedwater pH to about 9.0 as far as corrosion of iron and copper alloys was concerned struck the authors as possibly extracting a price particularly in zones of turbulent flow, in the way of wastage of ferrous and non-ferrous materials subject to erosive forces such as pump, regulating valve and piping parts.

Accordingly, ammonia, cyclohexamine and morpholine, all volatile compounds for pH control, plus sodium hydroxide, a non-volatile, were selected for evaluation studies on ferrous losses when they were applied.

Results indicated that "increases in feedwater pH for the purpose of reducing corrosion-erosion attack should be made with caution." The work further indicated that any advantages that are gained in the turbine may be lost in the other parts of the steam-water cycle.

The paper by Messrs. Geiringer and Hasselriis pointed out a number of reasons why they believe high temperature water is especially well suited as a heat recovery and heat distribution medium in power producing plants. It may be used directly in many process and space heating applications where the pressures, temperatures and weight of the water are not objectionable and where the equipment has been or can be designed for use with a liquid heat carrier. When so used, surprisingly small pipe sizes can be employed to distribute the heat.

When high temperature water cannot be applied directly, heat exchangers can reduce or transform the heat to the pressures and temperatures required by the application. In power plants with regenerative heaters, high temperature water power plants were claimed by the authors to produce a great deal more power than equivalent steam process heat power plants. To evaluate the role of high temperature water a coefficient of performance was established for the various cycles. It was defined as the ratio of the power output to the process heat delivered by the cycle. Then this comparison ratio was applied to a steam process heating and power cycle, a high temperature water process heating and power cycle and also an example of balancing power production with heat requirements.

The symposium on demineralization included three specific installation experiences, two of which concerned a 1500-psi boiler plant of the Gulf States Utilities Co., and the third discussed the Albany Steam Station of the Niagara Mohawk Power Corp. The fourth and final paper of the symposium covered the expected life of anion exchangers under various design and operating conditions.

The Gulf States Utilities experience with a demineralization plant built for 1500-psi boiler service was divided into its design phase, presented by **C. R. Stewart,** mechanical engineer, Stone & Webster Engineering Corp., and its operating results, handled by **W. B. Gurney,** efficiency engineer, Gulf States Utilities Co. Mr. Stewart outlined the background of the 3500-gpm net capacity demineralizing plant. The high quality of feed-

water required and the unusual type of well water to be treated led to a thorough exploration of treatment methods. In addition the decision to operate the plant with the minimum of manual labor resulted in a design that called for exceptionally complete instrumentation and automatic controls.

One of the most interesting highlights of the paper was an illustration which showed the older, fairly large clarifying and softening plant handling river water up to about 4500 gpm and requiring most of the ground area for its process as contrasted to the very small, almost cramped, layout of the demineralizing plant of roughly comparable capacity but handling well water. All the major elements in the demineralizing plant were described with ratings and position in the overall layout.

Mr. Gurney very early established the problem facing the Gulf States Utilities Co. with its need to supply its neighboring industrial customers with more 135-psig process steam. The decision to go to 1500-psig boilers using 100 per cent makeup imposed heavy burdens on the water treatment plant. The two water sources—the Mississippi River or well water from a 2000 ft strata—indicated well water would lend itself to a demineralization plant that would require a much lower initial investment than the river water with its dependence on preclarification and filtration.

The major difficulties of the well water were high sodium and silica contents and an occasional trace of hydrogen sulfide. So pilot plant tests were run off under a variety of conditions to furnish data on how best these well water problems could be handled. The pilot plant consisted of four glass cylinders, 4 inches in diameter, 48 inches tall, with a home-made vacuum degasifier between the cation and anion tubes.

Mr. Gurney's paper was rich in the procedures used and the various tests carried out. A number of rinse waters, rates of regeneration, strengths of regenerants were tried on both cation and anion resins. Operating procedures were closely studied and recommendations were advanced. Water treatment handling methods were also included.

Thomas Finnegan, chemical engineer, Niagara Mohawk Power Corp., and **Durando Miller,** assistant technical manager, Permutit Co., teamed up to describe the automatic mixed bed demineralizing plant at the Albany Station of Niagara Mohawk. This station has four 100,000-kw units operating with steam at 1450 psig and 1000 F with reheat to 1000 F at 415 psia at full load. Boilers, turbines and auxiliaries are essentially the same as at Dunkirk where an evaporator and evaporator condenser were installed with each unit.

Considerable capital expenditure was saved by the demineralizer. Further, the cost of demineralized makeup is expected to run less. When the demineralizer is compared with an evaporator in a cycle in which steam for evaporation is taken from the point most favorable for a low heat rate and an evaporator condenser is used, there is little difference in the heat rates using both processes. In this analysis it was about 2 Btu's in favor of demineralizing.

The operators were said to like the availability of the demineralizer. With its independence from the heat cycle there has been no difficulty in getting enough water to fill the boiler after shutdown. During normal operation there has been little or no blowdown because the

boilers operate with but a few tenths of a per cent make-up and less than 100 ppm of total solids. The demineralizer, though, has always provided water at loads where the evaporator would not be available.

The mixed bed rather than the two-step process was selected because it gave an effluent with a lower electrolyte concentration than the two-step process. Also when a two-step demineralizer goes into service after a period of idleness, the effluent contains appreciably higher solids and silica than normal and may require rinsing to waste for a short while until solids and silica drop to normal. The conductivity of effluent from a mixed bed becomes normal in a minute or less and requires no rinse to waste. In a station designed for very low makeup this factor is important.

A number of tests and studies were conducted to check capacity of the resins in the mixed bed design. As a result interesting data are advanced on performance factors for this class demineralizer. All indicated design or operating changes that were instituted were aimed at furthering automatic operation.

Louis Wirth, Jr., of the Ion Exchange Division of National Aluminate Corp., handled the fourth and final paper of the session. His paper was fundamental in nature and reported on the several factors which operating data indicated had a significant influence on resin life. The factors so singled out were held by the author to allow a coordinated approach in estimating the useful life of highly basic anion exchangers.

In Mr. Wirth's opinion the selection of the proper ion exchange resin type for the water supply to be treated determines to a large extent the useful life and the operating costs of the resin. Next, reducing the oxygen content of the water passing through the anion exchanger considerably increases resin life. Organic matter, though, should not be confused with the factors affecting normal degradation of highly basic anion exchange resins. Rather, organic matter raises problems of its own in terms of resin capacity shortages and poor water quality.

Several of the deionizers under study were felt to be not sufficiently conservative in design to assure adequate operating exchange capacity. More conservatism of design, in the author's opinion, should be encouraged and it can be by a careful preparation of specifications.

The third scheduled meeting on water technology was divided between two papers. The first by **Dr. R. C. Ulmer,** research director, Combustion Engineering, Inc., outlined the water problems in the nuclear power field. The second paper by **H. M. Rivers,** director of engineering service, and **S. R. Osborne,** staff engineer, Hall Laboratories, traced the interlocking advances in design of boilers and progress in solving boiler water treatment difficulties.

Dr. Ulmer pointed out that radiation, which is always present, was not only hazardous but decomposed the water itself and the materials normally used in its treatment. The problem is further complicated in that many nuclear products and fission products are highly radioactive and the activity persists for many years.

Decomposition of water and aqueous solutions by radiation results in the formation of H_2, O_2 and H_2O_2. Essentially the action is one of irrigation. Back reactions occur resulting in the establishment of a steady-state level of activity.

To date, most nuclear power plant systems have involved separate cooling and steam generating systems. Water or liquid metal from the reactor cooling system is passed through the steam generator. Even though metal separates the two fluids, radiation passes through and imparts radioactivity to the water and steam. In the so-called homogeneous reactor system the induced radioactivity may be at a very high level. Pure water has a very short-life radioactivity so the purer the water in the system the better the results.

Some consideration is being given to a direct system for cooling-moderating and steam generation in a nuclear power system. Prevention of carryover then becomes of even more importance. In closing, Dr. Ulmer emphasized that many water problems still remain unsolved in the nuclear power field but the answers will come in time.

The Rivers and Osborne paper proved an interesting recount of the progress both boiler manufacturers and water-treatment firms have scored over the years. As the authors put it, the past three decades have witnessed many major advances in the field of steam generation. Boiler makers have provided industry with new and improved methods and equipment for extracting more energy from fuel. Water specialists have similarly created more economical and better treatment methods to increase on-the-line time of equipment.

Since the goals of both were held by the authors to be inexorably linked, a plea was made that boiler maker and consultant work together in providing boilers and water treatment of compatible design for new installations. An example was cited to prove the effectiveness of such a working team.

The water technology session, No. 4, was a three-paper one shared by **S. B. Applebaum,** manager of the water treatment division of Cochrane Corp., and **B. W. Dickerson** engineering department, Hercules Powder Co., as joint authors of the first paper on silica removal by salt splitting without any demineralizing, two Graver Water Conditioning Co. engineers, **M. Lane,** technical manager, and **J. H. Duff,** chemical engineer, who discussed some chemical aspects of hot-process, hot-zeolite plant performance and **E. C. Fiss,** chief chemical engineer, Duke Power Co., who recounted his company's experience with hydrazine.

Messrs. Applebaum and Dickerson presented a very informative report on a joint research project of their respective companies to find a possible third method of silica removal. This method—salt splitting—is an entirely different approach from demineralization, widely accepted by the high pressure, low makeup plants of the public utilities, or from the hot lime zeolite treatment, popular among the industrial plants with operating pressures between 500 and 1000 psig.

The same strongly basic anion exchange resins that are used in demineralizing following cation exchangers on the hydrogen cycle are also used in salt splitting. This means they can adsorb strong and weak acids as well as split salts or exchange anions for chloride or hydroxyl in the resin. Salt splitting does not affect the cations present. Therefore, hardness must first be eliminated or converted to sodium.

After the chemistry of the process was established the research work was aimed at the following objectives: (1) effect of decreasing caustic soda in the regenerant on effluent quality and capacity; (2) effect of using reclaimed caustic soda from a previous regeneration as an initial step in a succeeding regeneration; (3) effect of heating of caustic soda; (4) settlement of whether silica regenerated off the resin is in balance with silica removed from the water so silica does not accumulate on the resin; (5) determination of resin stability in the process; (6) a study of pilot plant operation to identify possible trouble spots in full scale operation so corrective measures can be taken before full scale building.

The results of the above research led the authors to these conclusions. Its field of application will usually be for boiler pressures from 500 to 1000 psig and for raw waters rather high in silica and low in dissolved solids. Its operating costs will be lower than demineralizing but higher than hot-lime zeolite. Total investment will be lower than either demineralizing or hot-lime zeolite so an economic study will have to be run for each individual installation on fixed costs against operating charges for the least expensive treatment.

The following paper on water technology presented by Messrs. Lane and Duff on the subject of hot-process, hot zeolite plant performances did not compare it with other treatment methods but was directed toward releasing new information helpful in making treatment selections, plant designs or plant operating techniques. Four major factors were considered: the effect of applied turbidity on zeolite unit performance, zeolite effluent total hardness, resin particle size, calcium and carbonate ion relationships and treatment calculations, silica reduction calculations.

The authors proceeded to report on their findings for each of these four factors. A sticky type of carryover or turbidity source greatly affected the hot process system since it formed a binder sludge that cemented the sulfonated styrene resin up near the top of the tank. A subsurface scrubber did combat it. Sodium aluminate has been a valuable aid in many plants producing lower turbidity settled water. The problem, though, is less likely to occur with filters and when it does it is good practice to install sub-surface scrubbers on the filters.

There are many factors that influence total hardness in a softened effluent. These are held by the authors to be the major influences since all the others can be met in a well designed plant. The amount of leakage increases rapidly with salt dosages below 6 pounds per cubic foot which the authors believe represents the minimum safe design dosage.

Resin particle size may decrease in effective size over a period of service (as much as 2 years) but resin capacity does not seem adversely affected nor does the loss of bed by attrition. Further, by operating at temperatures no higher than 250 F, hydration and subsequent high head loss from swelling of the resin bead does not develop.

The authors presented curves, tables and examples to assist in predicting effluent hardness and alkalinity for hot process treatments ahead of hot zeolite.

The paper by Mr. Fiss on hydrazine experiences in high-pressure boilers of his company's system was prefaced with the background of his company's policy to employ minimum chemical treatment for boiler feedwater. Evaporators up until 1946 gave mineral-free water and coupled with tight condensers to avoid contamination kept scale formation within manageable limits. Deaerating equipment controlled oxygen corrosion.

By 1946, though, corrosion troubles developed and a sodium sulfite treatment was installed. But the undesirable properties of sulfite such as its decomposition to sulfide and its tendency to seep around hand-hole gaskets, valve stems and pump glands, resulted in corrosion and scale formation and the resultant maintenance was held excessive, particularly for 900 psig boilers.

For some time eight higher pressure boilers subsequently put in operation were run without sulfite treatment but with special emphasis on good deaerator operation, and treatment of the evaporator feedwater for oxygen and carbon dioxide removal was initiated. Several chemicals were tried and hydrazine seemed most promising. The first trial treatment was made in a 450 psig, 380,000 lb per hr boiler in 1951 and it was found that hydrazine could be established and maintained in the boiler without observed ill effects.

Mr. Fiss went on to describe the equipment employed to feed hydrazine into the boiler feedwater, the control analyses for hydrazine treatment and regulation, and the handling precautions deemed necessary.

In summation the author listed several features that his company's experience indicated for hydrazine. He believed the chemical has definite advantages as an oxygen scavenger in high-pressure boiler service, but proved somewhat difficult to control within desirable limits.

Industrial Boilers

Carl E. Miller of Combustion Engineering, Inc., presented a paper entitled "Some Economic Factors Influencing Industrial Boiler Development." To obtain lower steam costs in the face of rising labor rates, full advantage should be taken of shop fabrication; automatic controls should be used wherever possible; and equipment should be selected which is capable of being operated for long periods without shutdowns.

Examples were given of several installations which use by-product and waste fuels. One showed a typical arrangement for burning blast furnace gas, coke breeze and oil at a steel mill. Others described steam generating units for burning cellulose fuels on spreader stokers and for burning a combination of organic residue, coal and gas.

In connection with reduction of costs, Mr. Miller mentioned the practice of shop fabrication of insulated air ducts. This eliminates some of the costly facilities otherwise necessary for erection and permits application of the insulation to the inside of the duct which offers the advantage of lower maintenance.

One way of offsetting higher fuel costs is to use higher efficiency units. In connection with the application of air heaters, the split type was proposed as one which simplifies cleaning and reduces replacement costs when corrosion occurs. Steam air heaters are finding increased use to maintain higher incoming temperatures at all loads and to reduce plugging problems.

"Industrial Operating Experience with Cyclone Boilers" was the title of a paper by Leo L. Moran of

The Dow Chemical Co. The power plant at Midland, Michigan, is similar to a base-loaded installation in that steam and power loads do not vary more than 10 per cent week by week, around the clock. There are five B. & W. cyclone-fired boilers which generate 400,000 lb of steam per hour at 1250 psig. No induced-draft fans are installed.

Mr. Moran outlined some of the difficulties encountered in feeding coal to the first unit which went into operation in 1949. In the early months of operation trouble was experienced with the slag handling because of intermittent firing. The second and third boilers were installed in 1950 and were equipped with different types of feeders, coal conditioners and ash-handling equipment. Little trouble was experienced in placing these boilers in service in a new building having greater accessibility than that in which the first unit was installed.

In changing from Pittsburgh No. 8 Seam coal to high-ash mid-western strip coal superheater plugging was encountered. To overcome this condition additional slag screen tubes and retractable wall blowers were installed. Availability of the boilers has been considered good, taking into consideration all the experimental factors involved.

Spreader Stoker Firing

"Operating Experiences with a Multi-Fired Stoker-Fired Boiler" was the title of a paper by G. G. Bachman of the Omaha Public Power District. A chain-grate stoker was removed from a boiler installed in 1937, and the arrangement of the furnace was modified to provide adaptability to spreader-stoker firing of an organic residue. The throat of the old furnace was eliminated and the volume was practically doubled. The screen-tube arrangement was changed, and a new two-stage pendant-type superheater with interstage desuperheating was installed. A mechanical-type dust collector and new forced- and induced-draft fans were provided. Several rows of overfire air nozzles were installed in the rear wall just above the stoker and in both the front and rear walls below the gas burners. The existing coal bunker was divided to permit the storing of both coal and residue.

Some difficulties were experienced in the early months of operation because the residue was not uniform in size. These problems were overcome through the substitution of a method of pneumatic injection for the original residue distributors.

During the first calendar year, the revamped unit operated 8200 hr at an average rating of 207,000 lb of steam per hour and at an average overall efficiency of 77.4 per cent. The latter was in line with the expectation for burning the high-moisture residue. Despite the lack of advance information and experience in burning the residue in combination with coal and natural gas, almost no difficulty was encountered in combination firing.

Gas Turbines

The very active field of gas turbine development was the subject of a two-paper meeting featuring gas tur-

bines for the power industry as presented by T. J. Putz, manager, gas turbine engineering, Westinghouse Electric Corp., and a new power cycle that combines a gas turbine with steam turbines as submitted by Louis S. Gee, mechanical engineer, West Texas Utilities Co.

Mr. Gee raised the very interesting premise that few engineers have made sufficiently detailed studies on older plants to realize that economies can be achieved through application of gas turbines to older plants. In the West Texas Utilities Co. a gas turbine added to the cycle of an old steam plant promised an increase in efficiency, an increase in overall plant economy, and the addition of 6611-kw generating capacity at an installed cost of only $76.37 per kw.

Weighing the low investment cost of old equipment with its high generating cost against new and more efficient turbine generators with a much higher investment cost but with a lower production expense has usually always showed a decided advantage in retaining older units. The advantage became even more marked if the old plant capacity and thermal efficiency could be increased with a resulting decrease in unit production cost. Topping steam turbines were the solution in the past.

Chief disadvantage to the above solution was the considerable investment for new high-pressure, high-temperature equipment plus the fact that the old equipment had to operate at high capacity and load factor since the topping turbine could not be operated economically alone.

West Texas studied its old power stations with their multiple boilers, their turbines using common headers and their practice of common feedwater heaters to receive extraction steam from headers common to all turbines. Steam was delivered to the turbines between 250 psig and 350 psig and superheated to 150 to 250 deg F, respectively. The result of the studies was the development of a new cycle to accomplish all the desired changes including a prime mover that could stand alone if circumstances so dictated, namely, a gas turbine.

The application of a gas turbine to a steam cycle with a waste-heat recuperator was by no means a new one, but the method of application and the resulting cycle, the author claimed, had no precedent. The new cycle incorporated the recuperator in the feedwater cycle next to the condenser hotwells or evaporator condenser which gave the maximum logarithmic mean temperature difference between gas-turbine flue gas and the condensate to be heated at the lowest condensate pressure. Incorporating a simple cycle gas turbine imposed in a steam cycle and utilizing the exhaust heat from the flue gas of the turbine, provided fuel can be obtained at a price comparable to that used in the steam plant, can give definite economies, Mr. Gee claimed.

Gas Turbines for Steel Plants

G. H. Krapf of the United States Steel Corp. presented a paper entitled "Gas Turbines for the Steel Industry" in which he reported on some combustion tests carried out by Westinghouse Electric Corp. at the Carrie Furnace of the Homestead Works of U. S. Steel. The purpose of the test program was to explore the possibilities of burning blast furnace gas in a gas turbine and to develop suitable equipment for such an application.

Actual operation was simulated as closely as possible with smaller mass flow rates. The combustor was one of the standard type used in a 5000-kw gas-turbine plant. Maximum pressure in the combustor during the tests was 15 psia. Initial tests showed that modifications to the gas admission nozzle were required to improve combustion and flame stability for full and part load operation.

Test results indicated that blast furnace gas can be ignited and burned with efficiencies comparable to those obtained when fuel oils or gases with higher heating values are used in gas-turbine combustors. No detrimental effects from burning blast furnace gas, such as combustor deposits or excessive corrosion, were encountered.

Studies were made of the corrosion properties of blast furnace gas dust at high temperatures on turbine blade materials. Using dust samples of double the normal concentration, little corrosion was noted on specimens of Stellite, 25–20 stainless steel and Inconel X blade test specimens. Other data indicate that there should be no erosion problem when the gas dust content is 0.015 grain per cubic foot or less.

Fuel Economics

The subject of fuel and particularly its economics as reflected in terms of availability, market price or trends is of prime concern to the general power field. There were four principal speakers covering oil, gas, coal and nuclear fuels in a session labeled Fuel Economics. **Charles J. Hedlund,** head, petroleum economics division, Standard Oil Co. of New Jersey, handled the role of oil in the fuel market; **Richard J. Gonzales,** director and economist, Humble Oil & Refining Co., spoke on the economic trends in natural gas; **George A. Lamb,** manager of business surveys, Pittsburgh Consolidation Coal Co., traced the future of coal in power generation; and **Walter F. Friend,** mechanical engineer, Ebasco Services, Inc., explored the possibilities of nuclear fuels for power generation.

Mr. Hedlund traced the importance of energy to civilized man's development and linked its use directly with the living standard of individual countries. From this starting point the author sketched the part petroleum has played in the energy markets of the world.

Some interesting statistics were presented on oil supplies and the major fields of use. One table in particular gave U. S. consumption in actual fuel units of energy by electric utilities for the major energy sources now available.

The R. J. Gonzales paper on economic trends in natural gas was a very comprehensive collection of statistics on this industry. Very early in the paper Mr. Gonzales declared that the largest contribution to additional domestic output of mineral energy in the U.S.A. since the war had been natural gas. Its increase in output had exceeded that of domestic crude oil which was a much larger source of energy at the end of the war and had gained 40 per cent since then. In 1953 the natural gas marketed had a heat content equivalent to 1.5 billion barrels of crude oil or 360 million tons of coal. Thus it supplied about two-thirds as much energy as either of these competing fuels and more than one-fourth of all domestic production of mineral energy.

Additions to gas reserves in discoveries, extensions and revisions of prior estimates have more than offset increased production. Yet proved reserves of gas now stand at about 22 times the annual output as against 33 times in 1946. The speaker held that as long as proved reserves continue to be maintained or increased it would be a mistake to count the life of the industry as only 22 years.

Some of the statistics Mr. Gonzales developed challenged the imagination. For example, the interstate movement of natural gas advanced from 1100 to about 4000 billion cubic feet between 1945 and 1953. Texas and Louisiana supplied about three-fourths of the interstate demand. By 1952 interstate receipts exceeded 400 billion cubic feet in Ohio and were around 300 million cubic feet or more in Illinois, Pennsylvania and California. Gas was used in 41 states in 1952, the only exceptions being Maine, Vermont and Rhode Island in New England, and Nevada, Idaho, Oregon and Washington in the West.

Mr. Lamb early established the fact that coal looks to electric power as its principal customer. Power generation growth has been well founded on performance. It jumped its utility generation from 39 billion kwhr in 1920 to 329 billion kwhr in 1950. All of which in the author's opinion gave support to the belief that the electric power market doubles every ten years. Such a rule of thumb means roughly 700 billion kwhr by 1960.

As Mr. Lamb mentioned, when generation reaches 700 billion kwhr annually, coal needs would total 140 million tons if water power, natural gas and oil retain their present relationships.

The coal industry has the fuel resources for this impending load and according to the author will probably continue to show labor improvements with the passing years. Bituminous coal output per man-day measured near 8 tons in 1953 according to the latest figures, about twice as high as it was in 1920. Mining capacity, though, should be planned. And to make this planning intelligent, Mr. Lamb made a plea for more participation by the electric utility industry.

Mr. Friend wound up the 4-paper session with a general treatment of the latest fuel energy source, nuclear fuels. He mentioned that this newcomer, barely 15 years old, represents the nation's largest enterprise if you take into account the prospecting, mining and processing of uranium ores as well as the development of method and facilities to achieve the release of nuclear energy.

This paper brought together some theory of nuclear reaction, properties of nuclear fuels, types of reaction, uranium prices and trends, costs per kilowatt hour and uranium ore prices.

For natural uranium metal, a hypothetical price named in non-classified technical papers during the past year by AEC representatives and members of the utility study teams was $35 per lb. Dr. R. P. Petersen, AEC chief of the industrial reactor branch, before the Proceedings of Atomic Industrial Forum, Inc., March 16, 1954, used the range of $50 to $70 per kilogram of uranium oxide containing 84.7 per cent metal, or $27 to $38 per lb.

For fissionable uranium—235, the cost figure appearing in a number of papers during the past several years has been $9000 per lb. At the March 16 meeting of the Atomic Industrial Forum $20 per gram was suggested or $4400 per lb, quite some drop from early estimates.

Prediction of future cost levels for nuclear fuels in the U. S. A., when such prediction becomes possible, will, according to Mr. Friend, have to take into account these factors: (1) effect of relaxation of atomic energy controls by modification of the existing Atomic Energy Act, (2) results of exploration programs to discover location, character and extent of uranium and thorium deposits, domestic and foreign, (3) technologic improvements in mining and ore-processing operations, (4) magnitude of future market for nuclear fuels for power generation and other peaceful uses, (5) effects of military programs, that is, a possible shift from fission principle to thermonuclear reaction for mass production of weapons, (6) international developments with respect to production, utilization and controls.

An advance type of breeder reactor using 50 per cent of the total natural uranium, Mr. Friend stated, would have negligible fuel cost regardless of the future price level of uranium metal. In comparison a coal-burning conventional power plant with 12,500 Btu fuel at $7 per ton with a station performance of 10,000 Btu per kwhr has a fuel cost of 2.7 mills per kwhr.

Industrial Plants

A fair amount of industrial flavoring was made a part of the program in two sessions, one sponsored by the National Association of Power Engineers. This last one featured three papers ranging from a discussion of scale modeling as a practical engineering and construction tool by **J. A. Carroll,** department head, engineering division, Procter & Gamble Co., through an address on selection, maintenance and piping practice in industrial plants by **Robert J. Pinske,** power plant engineer, Crane Co., to a treatment on planning and installing an electrical system in a rapidly growing industrial plant by **Hans Edergger, Jr.,** sales engineer, L. L. Weldy and Associates, and **M. W. Stehr,** supervising industrial engineer, power sales division, Wisconsin Electric Power Co.

Mr. Carroll opened with the comments that models have long been used in certain phases of engineering, architectural design or operator training to name a few applications. In such instances appearance is a prime consideration. The time and the cost involved in making such models a practical aid in detailed engineering had always made their use out of the question.

Recently, though, Mr. Carroll's firm engaged the services of a modeling concern that claimed it could build complicated industrial models in weeks rather than months. They employed specialized techniques for representing equipment and had learned where detail could be omitted without destroying the model's value as a study tool.

Once the accuracy of the model was established the practical problems of layout, aisle sizes, clearances, operators' convenience, pipe and conduit routing and layout, equipment and pipe support, location of ladders and platforms, valve locations could be definitely spotted and given the benefit of proper planning.

The author described in detail how the initial rather rough models are constantly refined to aid in piping studies and as checks against piping detail drawings until eventually the completed model becomes an aid to study of steam tracers, lighting fixture locations, late alterations and many other fine points.

Construction people similarly found the models valuable to them in their work. It proved of particular value to foremen in explaining and assigning work to craftsmen.

Mr. Pinske's material on selection, maintenance and piping practice in industrial plants was based on the results of a survey of 117 industrial plants. The survey was directed at appraising the level of maintenance in some plants but not to attempt to establish an average practice.

In view of the fact that piping represents from 10 per cent to as high as two-thirds the cost of the equipment it services, and piping maintenance expenditures for most plants average from $1/_2$ to 2 per cent of the sales dollar, the author expressed concern at the indifference to piping upkeep in many plants. The basis for such indifference, he believed, was the misunderstanding that rates piping components as stationary objects subject to little wear. Maintenance programs, as might be expected, varied all over the lot. About 35 per cent of the surveyed plants had some form of organized maintenance but 65 per cent had none except to make necessary repairs.

Where engineers controlled the maintenance operations, results were much better. Piping should be recorded on drawings and all piping modifications entered before a job is started. Ninety per cent of the surveyed plants kept no piping records. Many estimated their maintenance costs were comparable to other plants of the same size. But unfortunately no formula has ever been devised to predict what maintenance should cost. Efficiency and quality of maintenance and supervision could differ so much between plants that no comparison could be made. Further, there has never been any standard maintenance accounting ever set up.

Welded installations, in Mr. Pinske's opinion enjoyed many advantages. For example, 10 to 15 per cent of the total cost of a threaded installation should be added to take care of leakage possibilities. Further, welded fittings enjoyed reduced cost of hangers and supports, less insulation cost, no damage to insulation from leaks, freedom from shutdowns, strength of connections, neat appearance. But for any piping system Mr. Pinske urged adoption of an organized set of pipe standards for installation.

A second division of the industrial plants coverage was one on the economic aspects of power plants. Headlining this division were papers on the economic factors affecting selection and replacement of power plant equipment by **Gerald J. Matchett,** director, dynamic equipment policy research center, Illinois Institute of Technology, and the economics of the Hawthorne (Western Electric Co.) power plant rehabilitation presented by **C. E. Morrow,** engineer, power and service facilities engineering, and **R. F. Born,** mechanical engineer, Western Electric Co.

Mr. Matchett's talk was quite a sharp departure from the usual technical meeting presentation. He confined his paper to the economist's viewpoint in establishing the selection and replacement of power plant equipment. The measurement of economic efficiency in the power industry where a required energy output has been determined and the aim is to provide facilities for this output boiled down, in his opinion, to a selection of

the alternative that minimizes cost. Investment costs, he cautioned, loom large in the power industry as well as obsolescence.

In determining the proper evaluation of costs for replacement the author established this rule: costs that will be different depending on whether or not replacement is made are relevant. Unfortunately, as Mr. Matchett pointed out, it is impossible to draw up a list of relevant and irrelevant costs in advance since so many items are borderline and require close study and understanding of their application. To drive the point home, Mr. Matchett cited several illustrations of borderline instances.

The author carried the economist's approach still further and discussed investment charges and their ramifications, as well as variable or operating and maintenance costs.

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Messrs. Morrow and Born described an actual large-scale plant modernization program which they justified economically to management before undertaking the project. They recognized that light manufacturing, characteristic of most Western Electric Company's operations, had traditionally been one of high manpower costs and light power needs. But over the years the amount of power per worker was climbing and, since 1926 the time of the last power survey, had reached a level where investment savings per unit of power output were extremely worth while.

Accordingly, the economics of several modernization schemes were compared on the basis of annual operating costs including a fixed charge of 4 per cent. The number of years necessary for the annual savings credited to a plan to offset its increase in capitalization was taken as a criterion, and the plan accomplishing this in the fewest years was considered the best.

The technique was applied to the basic scheme and to the major pieces of equipment. For example, the increased capitalization and annual operating cost incidental to high pressure topping operation were estimated and depicted by charts. Incidentally, the tables and charts presented with this paper gave an excellent insight into large-scale industrial power costs.

Comparison of Steam and Diesel Plants

In answer to the question posed by the title of their paper, "Steam and/or Diesel?" **C. M. Stanley** and **S. K. Fosholt** of Stanley Engineering Co., Muscatine, Iowa, stated that there can be no simple answer that one type of equipment is better than the other. Both types have their place, and under certain conditions either is capable of operating at more favorable costs than the other. There is no elementary rule of thumb or formula which can indicate the type of equipment that should be selected. What is required for intelligent selection is the application of comprehensive engineering analysis and judgment involving both economic and engineering factors. The authors considered the competition between proponents of steam and diesel a healthy influence but urged that decisions rest upon sound engineering judgment rather than prejudice.

The authors based their paper on plants generating electrical energy without supplying steam for process or heating and limited their discussion to units not exceed-

ing 16,500 kw for steam and 3500 kw for diesel. Fuel requirements for diesel equipment vary only slightly with size, and in the range from 400 to 3500 kw an almost constant full load heat rate was shown. For steam equipment ranging from 1250 kw to 16,500 kw, with varying initial steam conditions, a 37 per cent decrease in full load station heat rate was noted between the smallest and the largest units. When both types of equipment have the same price of fuel delivered to the plant, diesel equipment shows a lower fuel cost per net kwhr, including lubrication, than the largest steam unit considered.

Probable construction costs were listed for the two types of plants. For a 450-kw diesel-electric generating station the range was $230 to $320 per kw of net capability; the corresponding range for a 3500-kw installation was $190 to $220. In the case of steam-electric generating stations, the range for a 1250-kw installation was estimated to be from $280 to $340 per kw of net capability; the corresponding value for a 16,500-kw installation was $170 to $195. It should be understood that these costs are average and may vary appreciably with design and with local conditions.

Among other factors discussed by the authors were reserve capacity requirements, fixed charges, pay roll costs, and maintenance costs. It was their judgment that maintenance costs for steam and diesel equipment are essentially the same under normal operating conditions, and that any differences which may occur are usually of such small magnitude that they seldom affect the decision as to type of equipment to be selected.

There are some engineering factors other than economic ones which frequently affect selection, particularly if the costs are at a stand off. Messrs. Stanley and Fosholt commented that construction time is usually shorter with diesel equipment, which requires less cooling water. Steam equipment generally involves fewer units and is capable of burning a wider variety of fuels. As far as reliability is concerned, there is little basis for preference, but the diesel is believed to have advantages in simplicity, space requirements, and starting time.

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A CORRECTION

The equations appearing on p. 49 of the March 1954 issue in connection with the article "Cooling Water Treatment" by J. I. Munson, the Permutit Co., should have all carried plus signs and not minus signs as published.

A house for tomorrow

When Bill Miller first talked to the architect about his new home he stressed his desire to put into it the soundest materials and the newest conveniences.

"I hope my grandchildren will be happy in this house," he explained. "New improvements come fast these days, so let's try to be a few years ahead in our planning."

"What fuel would you like to use?" asked the architect when the discussion reached the heating plant.

"I would prefer to use coal," answered Bill, "I understand it is the most economical fuel here, as it is in most areas. But I don't want my wife

to be a furnace-tender."

"With a modern, bin-feed stoker with thermostatic control," said the architect, "your heating will be completely automatic, as well as clean and convenient. And coal has some big advantages — it gives a steady heat, not an off-again-on-again heat. Then there's this for the fellow who looks ahead: I don't know how long these other fuels are going to last. Every year they have to drill their wells deeper, and we are becoming more and more dependent on foreign supplies. As these other fuels get scarcer, they are going to get even more expensive.

"But coal is another story. There is plenty of coal right here in the United States to last us for hundreds—maybe thousands of years. That's something to think about when you're planning a house with the hope that your grandchildren will still be living in it."

COAL
FUEL OF THE FUTURE

Chesapeake and Ohio Railway
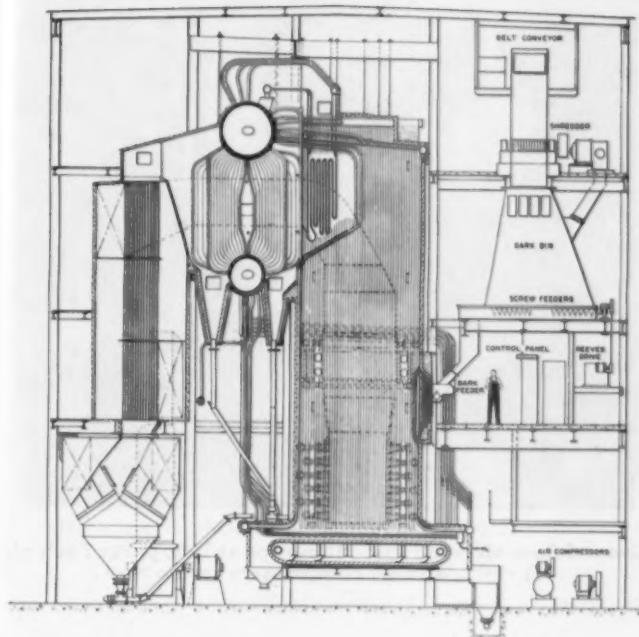
Cross-section through boiler and bark-handling equipment
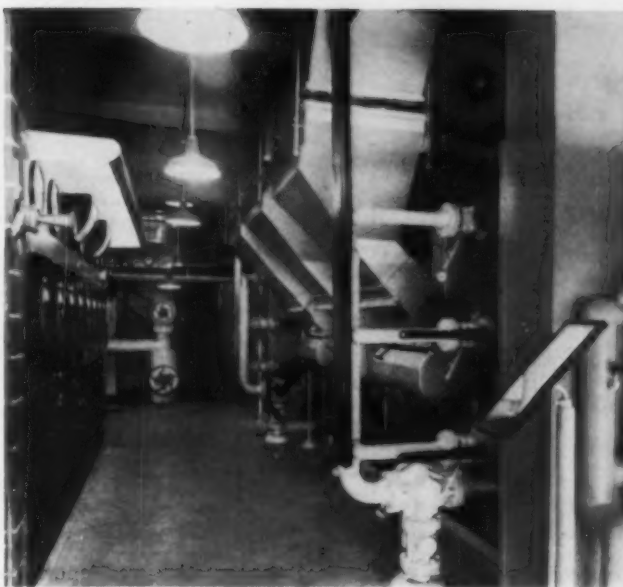
Firing aisle; bark feeders on right; instrument and control panel on left

New Bark Burning Boiler for the Hollingsworth & Whitney Company

At the Chickasaw Mill in Mobile, Alabama, a new bark-burning installation has just been completed. The author tells how the bark is prepared, how it is handled in the plant and how it is burned on a high-set spreader stoker. Other features of the plant are also described.

By A. B. STICKNEY
The Rust Engineering Company

IN an integrated pulp and paper mill a substantial portion of the steam required by the process can be generated by burning waste fuels. Consequently any increase in effieiency in burning the waste fuels is reflected in reduction of the purchased fuel. The waste fuels available in a sulfate process pulp mill are black liquor and bark. Burning black liquor is primarily a means of recovering the chemicals used up in digesting the chips to pulp, for re-use in digesting more chips, and the generation of steam is incidental, although valuable. Burning bark not only provides needed steam, but obviates the difficult disposal problem of a bulky waste material which is subject to spontaneous combustion.

The principal raw material for pulp is wood which, in the South, arrives at the mill in the form of logs about 5 ft., 3 in. long and of varying diameters. These logs are fed to barking drums, which are large horizontal cylindrical revolving drums with perforated sides, with various internal projections to help lift the logs higher before dropping them. The logs are fed into one end of the revolving drum. They are carried up the side and fall back, gradually feeding along the drum. A log falls many times in progressing the length of the drum. The abrasion of log falling against log peels off the bark, so that when the log finally leaves the discharge end of the drum to the conveyor carrying it to the chipper, it is largely bark-free. The bark falls through the slots in the drum into a hopper whence it is removed by a conveyor. From 500 to 700 lb of bark, containing from 30 to 50 per cent moisture, are recovered per cord of wood fed to the drum. Depending on the species of tree and the season, the size and toughness of the pieces of bark vary greatly. At worst they are the length of the log, 5 ft by 4 to 6 in. wide, with a toughness approximating leather.

Older Methods of Bark Burning

In the past the bark as it came from the drum was burned by either the pile or overfeed grate method. In the pile method it was dumped through holes in the top of a dutch oven onto a flat stationary grate, where it built conical piles which burned on the surface. In the overfeed grate method it was fed onto the steeply sloping top section of an undulating grate which gradually became less steep in its lower sections. The bark fed down from section to section, burning as it traveled, the ash being discharged at the bottom, whence it was raked out, quenched and removed. In recent years many installations have employed low-set spreader stokers to burn bark, first shredding the bark into small enough pieces to be handled by the spreader.
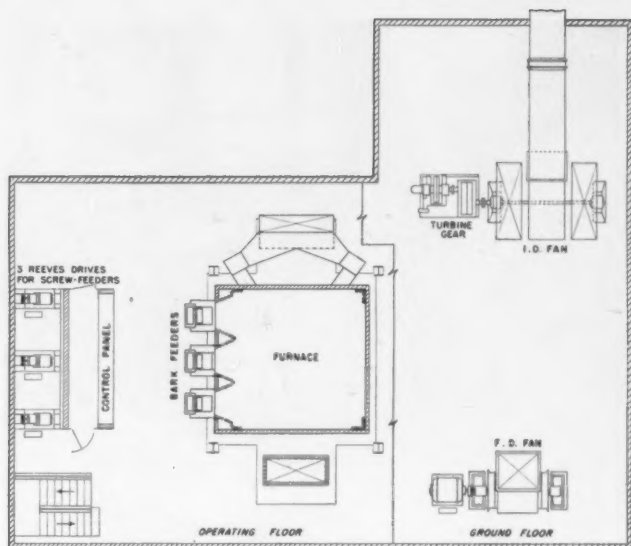
Plan view showing portions of the ground and operating floors

Ground floor showing fuel-oil pumps at left, part of ash pit at right, and air compressors to the rear

Development of New Design

On January 26, 1954, the Chickasaw Mill of The Hollingsworth & Whitney Company, at Mobile, Alabama, placed in operation a new bark-burning boiler embodying the latest steps in the evolution of units for the more efficient and economical use of this fuel. The installation, designed jointly by The Rust Engineering Co. of Pittsburgh, Pa., Combustion Engineering, Inc., and Hollingsworth & Whitney Co., and erected by The Rust Engineering Co., employs a Combustion Engineering steam-generating unit of a type developed specifically for this service. The prototype unit, incorporating many facilities for experimenting with variations in operating techniques, was installed in 1951, and has been described by Ellwanger[1] in a TAPPI paper, and by de Lorenzi[2] in an ASME paper. Based on experience with this unit, the manufacturer has eliminated many of the experimental features, and has made various changes in developing a standardized design, of which several have been sold.

Since the barking drums work only part of the 24 hours, and are subject to interruptions during their working day, economical utilization of installed boiler capacity dictates use of a supplementary fuel, in this case gas, with oil standby.

The design capacity is as follows:

Burning bark alone............	130,000 lb per hr
Burning gas alone.............	160,000 lb per hr
Combination firing:	
Bark......................	100,000 lb per hr
Gas.......................	60,000 lb per hr
Combined total................	160,000 lb per hr

The unit here described is the first of the standardized design to go in service, although one other unit based on the prototype preceded it.

The present unit employs a high-set spreader, the throwers being 15 ft above the grate in a 46-ft high furnace. Shredded bark is thrown into the furnace at this level, and the first step in burning it is direct evaporative drying by contact with the hot products of combustion from the bark burning below it. As the bark dries it falls into a turbulent zone, where much of the air for combustion is introduced at high velocity through six levels of tangential nozzles. Successive levels are tangent to an imaginary cylinder in the furnace in opposite directions, so that as the bark falls through successive zones the tendency is to move it first clockwise, then counterclockwise, then clockwise again, etc. This leads to a high degree of turbulence and also prolongs the period the bark is in suspension. The high turbulence keeps removing the products of combustion from the burning surface and bringing new oxygen to it, permitting completion of combustion with a minimum of excess air. As a result, much of it burns in suspension, and only a fraction of it ever reaches the grate, where it is burned in a conventional way. Since only a small part of the fuel reaches the grate, and that has been thoroughly dried, only a portion of the total combustion air need be, or is, introduced through the grate. The grate is of the continuous-ash-discharge type, discharging to the front, with a long burning and cooling period on the grate before it is discharged to the ash pit. Actually combustion is remarkably complete, and most of the ash discharge consists of impurities in the bark, such as windborne sand and the like.

The products of combustion rise through the evaporative zone where the fresh bark is fed in, furnishing the heat for this operation. Evaporation of the moisture in the bark results in a low gas temperature entering the convection section of the boiler. Under these conditions it is doubly important to have low excess air to minimize both the quantity of stack gas and its temperature at this point.

Gas or oil is introduced through tilting-type burners above the level of the spreaders. Air ducts are split after leaving the preheater and separately dampered so that air can be separately regulated and proportioned to gas and bark as required.

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[1] R. Ellwanger, "Suspension Burning of Bark Refuse," Richmond, Va., Meeting of Technical Association of the Pulp & Paper Industry, September 26, 1951.

[2] Otto de Lorenzi, "Turbulent Suspension Burning of Wet Woods and Other Fuels," ASME Annual Meeting, New York, December 1, 1952.

Bark bin; note accessibility and open construction

View from outside of building showing dust-collector hoppers and induced-draft fan

Boiler Details

The boiler is of single-pass design, with $2\frac{1}{2}$ in. tubes on $3\frac{1}{2}$-in. centers, the tubes being swaged to 2 in. where they enter the drums. Design pressure is 725 psig; operating pressure, 590 psig at superheater outlet; and operating temperature, 750 F, with feedwater at 274 F. The furnace is fully water-walled. Soot hoppers are provided in front of and behind the mud drum. No sootblowers are installed, but wall boxes are provided for their future installation if required. It is not expected that they will be needed unless and until substantial use of fuel oil is required.

From the boiler the gas flows down through an air preheater to a Prat-Daniel dust collector which is split, the gas from each half going to its own side of the induced-draft fan. The latter is at ground level to one side of the boiler, which permits a very compact arrangement. Ash from the dust collector and soot hoppers at the mud drum is reinjected just above the grate and below the turbulence zone, so that it is deposited at the back of the grate. With the low-velocity air through the grate, the ash is carried forward on the grate, burning out enroute and finally being deposited in the ash pit. The induced-draft fan discharges through a breeching to the stack

serving the old boilers. This breeching is not shown in cross section drawing, p 57.

Parallel Operation

The new boiler will operate in parallel with both black liquor units and gas-fired power boilers. The steam output of the black liquor units is governed by the process. The power boilers are under full automatic control to maintain steam pressure. Therefore it was decided to base-load the new unit, with provision for allowing future conversion to conventional pressure control. A base load is set on the master, and the gas flow is proportioned to supplement the bark feed to maintain this base load, which must always be greater than the steam available from the maximum instantaneous bark feed. Air flow to the gas burners is metered and proportioned to the gas flow. Total air flow is measured by the pressure drop across the preheater, and the forced-draft fan, inlet louvres are adjusted to give the total air required. Since different amounts of air are required per pound of steam generated from bark and gas, the controls subtract the air to the gas burners from the total air, and adjust the total to proportion the balance to the bark feed. An oxygen recorder is included as a guide to the operators in making adjustments and as a check on the performance of

Top of boiler; bark shredder in rear
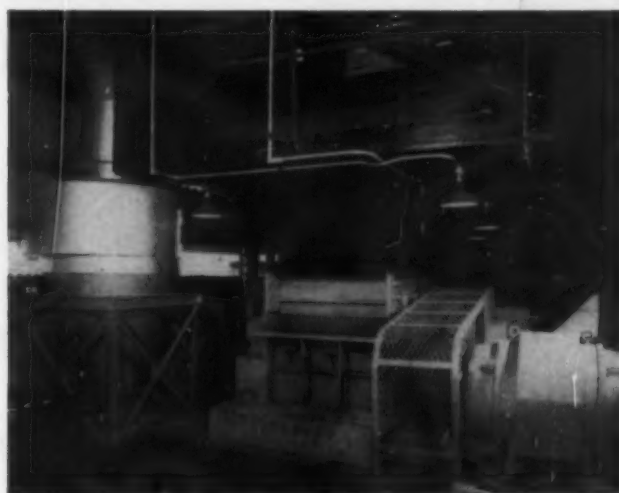
Bark shredder and bark bin dust system

the controls. Dampers controlling the supply of air to the stoker grates are pneumatically operated by hand from the control board, since air supply is based on observation of the grates, and distribution between stoker zones is by manually-operated dampers. The speed of the turbine-driven induced-draft fan is regulated to maintain furnace draft. Controls and instrumentation are by Bailey Meter Company, who also provided the three-element feedwater control.

Predicted performance contemplates the generation of 2.45 lb of steam per lb of 50 per cent moisture bark, at 130,000 lb load. This represents an efficiency of 65.8 per cent. Considering that the inherent loss due to moisture in the fuel is 22 per cent, this is excellent performance. It is based on 20 per cent excess air and 445 F stack temperature. On gas at 160,000 lb load predicted efficiency is 80.4 per cent, with 15 per cent excess air and 422 F stack temperature. Predicted efficiency of dust collector is 94 per cent.

Bark Handling

The incoming bark is diverted from the chutes to the bins serving the old over-feed-grate bark-burning boilers. It is transferred by gravity to a short belt conveyor with a Stearns electromagnetic pulley to separate tramp iron. The discharge is to a bifurcated chute with a flop gate, which feeds selectively to either of two bark shredders. These are Montgomery Blo-Hogs, which operate on a combination of hammer-and-scissors principles. They are located on the floor serving the steam drum. They discharge to a Fairfield live-bottom bark bin. This has 18 screw feeders covering the entire floor which is 18 ft wide by 12 ft long. The bark is fed across the bin toward the boiler, where it discharges into three chutes feeding the three spreaders. The six screws feeding each spreader are gang-driven through a Reeves variable-speed drive, with speed indicator and control on the instrument panel. The sides of the bin slope in sharply as they rise, on all four sides, to minimize bridging. An exhauster system and cyclone are provided to maintain a slight suction in the bin and minimize dust. While it

would be possible to store bark and feed it at a uniform rate over a 24-hr period, the size of storage would be enormous. A cubic foot of bark will make about 50 lb steam, so that at capacity on bark (130,000 lb per hr) the fuel volume is 2600 cu ft per hr. Bark tends to bridge and removal from storage, particularly when it has been allowed to settle for a period and pack, presents problems even when using "live-bottom" bins. In this case a storage of about 20-minute capacity is provided to permit evening out and gradual changes of bark feed, and the bark is supplemented with gas.

Oil pumps and heater, instrument air compressors and receiver, and Hankison Condensifilters are on the ground floor under the operating aisle. A United Conveyor sluicing system to handle ashes from both the old bark-burning boilers and the new unit is in a trench in this floor. The ash is sluiced to a low region adjacent to the plant, adequate for many years to come by extension of the sluice pipe. The existing feedwater treating and pumping equipment is adequate to handle the new requirements, so no new facilities are provided. Feedwater lines come from the existing header, and steam connections are to existing headers. Electrical distribution is from a vault on a mezzanine of the ground floor, immediately below the operating floor.

The building is of the semi-outdoor type, with 8 ft, 6 in. louvres projecting 6 ft, on 8 ft vertical spacing. Concrete floors are provided in the operating areas, and grating floors at the sides and rear of the boiler. A corner stairwell is provided from top to bottom, with access at all levels to the adjacent old boiler house.
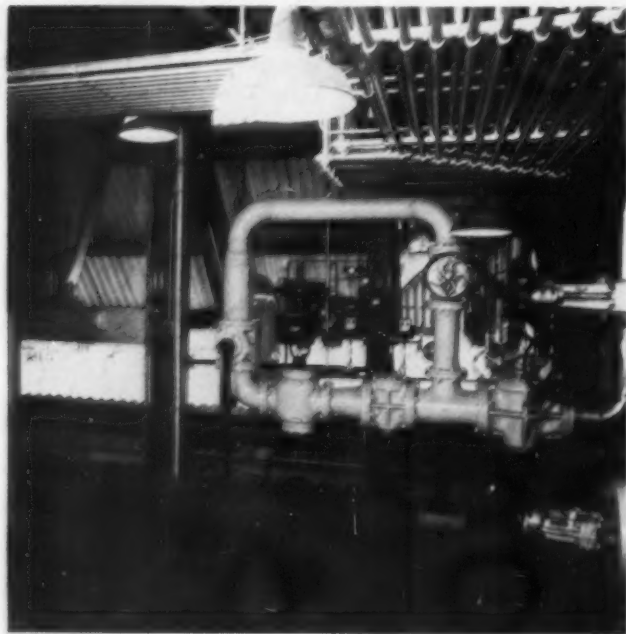
Gas control system located on operating floor
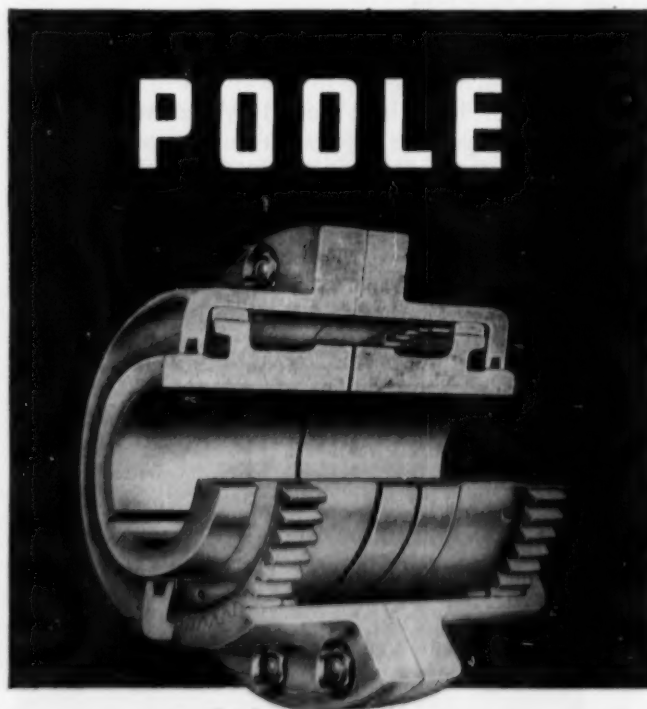
General View of Meredosia Power Station
Central Illinois Public Service Co.
Sargent and Lundy
Consulting Engineers

Bartlett-Snow
coal handling
at *Meredosia*

● The illustration above shows the first 100,000 KW unit of a plant which is to be extended into a 200,000 KW station. All coal handling equipment including the receiving and reclaiming hoppers and grillage, duplex feeder, conveyors, galleries, breaker screen and all supporting structures were fabricated in our shops, and installed by us, to Sargent and Lundy's specifications. For maximum efficiency and fixed unit responsibility, let the Bartlett-Snow coal handling engineers, with their long experience and complete facilities, work with you on your next job.

Belt Conveyor in Tunnel
Handling Coal from Track Hopper

Drive for Collector Belt Under Breaker
the Refuse Belt and Automatic Sampler

DESIGNERS

FABRICATORS

BARTLETT B-SNOW
CLEVELAND 5, OHIO

ERECTORS

ENGINEERS

"Builders of Equipment for People You Know"

Steam Purity Determination

I. Evaluation of Test Results

This is the first of a series of three articles dealing with the determination of the purity of steam from modern boilers. In this article, inconsistencies in current steam purity test values are discussed and suggestions given for logical evaluation of such data. In the second, methods will be outlined for obtaining test data to facilitate interpretation and evaluation of test results, and in the third, typical test results will be analyzed in some detail.

By P. B. PLACE

Combustion Engineering, Inc.

THE purposes underlying this series of articles are twofold. On the one hand, it is desired to point out inconsistencies in current steam purity test results and suggest the use of logic in the evaluation of such results. On the other hand, it is hoped to stimulate curiosity and research toward better methods of sampling and testing. There is no intention of being critical, for considerable work has been and is being done to insure reliability of test results. Until better methods are available, current methods can and must be a satisfactory guide for boiler operation. But they will be a better guide if these limitations are recognized.

There are two methods for testing steam for impurity, the gravimetric and the conductivity methods. The gravimetric method, because of the elaborate apparatus and the time required to complete an analysis, is not suitable as a plant control method. The conductivity method requires degasification of the sample and does not measure un-ionized constituents. The conductivity measurement itself is highly accurate, and there seems to be no good reason why conductivities of 0.2 mmho cannot be measured as accurately as conductivities of 2.0 mmho. The problem is to obtain a truly representative sample of steam. The purity of steam delivered by modern boilers is generally determined by conductivity tests and expressed in terms of parts per million (ppm) of solids impurity in steam.

What Test Values Represent

There are a number of observations on current impurity test results that arouse interesting speculation as to what these values actually represent and it is one purpose of this article to subject them to logical analysis.

Because of the emphasis on solids carryover, there is a tendency to forget that carryover from a boiler is primarily a liquid carryover process. The principal exception is the volatilization of silica at the higher operating pressures. With the exception of steam washers, drum internals are liquid-from-vapor separators and effect no separation of soluble solids from vapor or liquid.

With the knowledge that drum internals are liquid-from-vapor separators, it is reasonable to expect that if a given design of drum internals can deliver a one ppm steam with a boiler water concentration of 2000 ppm, then the same design should deliver a 0.25 ppm steam with a boiler water concentration of 500 ppm, other operating conditions being the same. Liquid conditions in the separator system being the same under the same operating conditions, and liquid separating efficiency being fixed by the separator design, it follows that the same amount of liquid carryover at different boiler water concentrations must result in a steam having proportionately different solids impurity content. This relationship, of course, does not hold at concentrations above which severe foaming may take place.

Since the effectiveness of separating equipment might logically be considered dependent on flow velocities, it would seem reasonable to make the assumption that liquid carryover and resulting impurity in the steam vary with boiler rating, probably increasing with increase in rating, when boiler water concentration and other operating factors are held constant.

But the facts do not bear out this assumption. Many tests on boilers over a wide range of rating, pressure, and boiler water concentration prove that any such relationship between rating, concentration, and impurity test value is the *exception*. In practically all cases, the impurity test values remain essentially *constant* regardless of normal changes in operating conditions. There are some instances where the impurity values may even follow less logical trends, such as decreasing with increases in rating and/or concentration. In those exceptional cases where the impurity test values do increase with increase in rating and increases in concentration, leakage in drum internals, foaming or some other cause of liquid carryover usually accounts for the exception. For example, although an individual boiler may deliver steam of apparently constant impurity under a variety of operating conditions, similar boilers and internals in different plants may deliver steam of apparently different purity under comparable operating conditions.

Typical Test Results

A few examples of typical test results will bear out these inconsistencies. Fig. 1 shows a selected case where degassed steam impurity was relatively high at 1$\frac{1}{2}$ ppm. It will be noted that, at more or less constant rating,
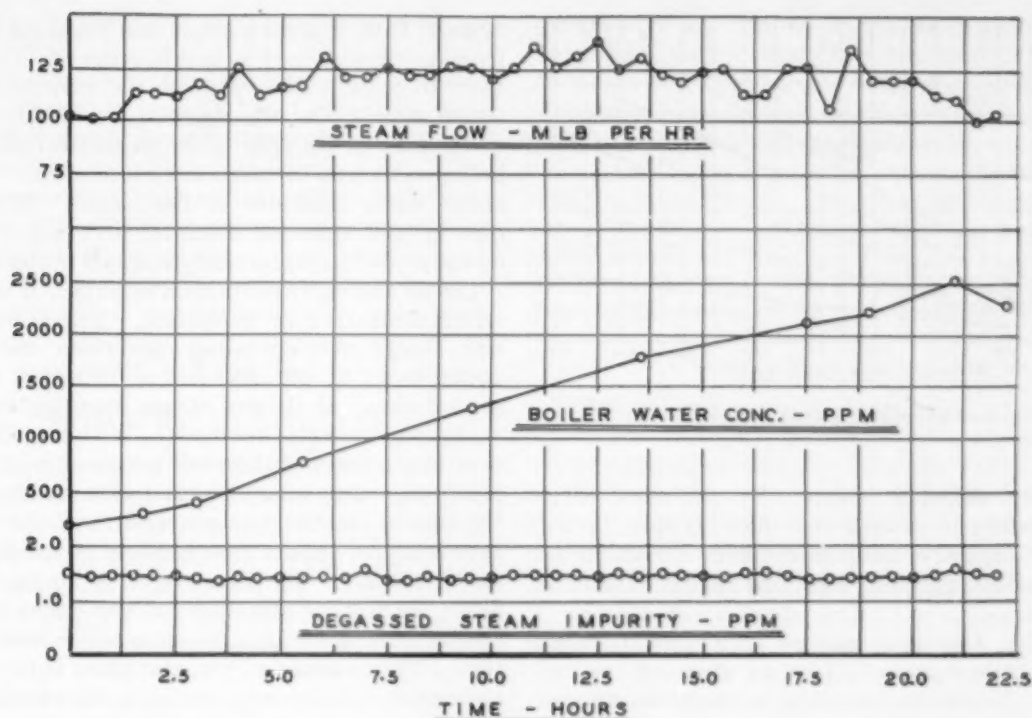
Fig. 1—Typical test results

boiler water concentration was increased tenfold without appreciable change in the test value. If the $1\frac{1}{2}$ ppm impurity value is considered correct for the 250 ppm concentration, then it should have increased to 15 ppm when the concentration was increased to 2500 ppm. Degassed steam test values are usually much less than $1\frac{1}{2}$ ppm but it is evident in this case that the impurity in the steam cannot possibly be anywhere near $1\frac{1}{2}$ ppm even though accepted test methods were used for its determination.

In another case, two units of similar design, with similar internals, and operating under similar conditions of pressure, rating and concentration, but in different locations, gave test results of 0.8 ppm degassed in one case but only 0.2 mmho conductivity undegassed in the other case. There is no reason to expect any difference in steam purity from the two units.

Still another striking example was a case where sampling and degasification equipment were better than average. With the boiler on bank, venting about 10,000 lb per hr of steam through the superheater, the degassed conductivity was 2.5 mmho with only 250 ppm boiler water concentration, yet with the boiler on the line with 370,000 lb per hr load, and 1300 ppm boiler water concentration, the conductivity was 2.2 mmho. The latter value slowly decreased to 1.6 mmho after several weeks continuous operation with rating up to 400,000 lb per hr and concentration at 1500 ppm.

Causes of Inconsistencies in Results

There are three phases of this problem that might be suggested as sources of these inconsistencies.

1. The mechanism of carryover and its distribution in the steam.
2. The process of sampling
3. The methods of test

The mechanism of carryover is generally accepted as a simple entrainment of boiler water in the steam, prob-

ably in the form of fine mist or spray. The normal impurity in commercial steam is the result of a small part of this entrained moisture escaping separation in the drum internals. That this mechanism is essentially correct is indicated by two observations:

1. The conductivity of steam samples that are known to contain boiler water moisture registers expected variations with changes in rating and boiler water concentration.

2. Minor carryover, as a result of leakages in the drum internals, can be reduced by sealing up the leakages. Thus the possibility of volatilization of soluble salts, comparable to silica carryover, does not appear to be an answer to the problem.

Distribution of carryover in the steam is a factor which undoubtedly becomes more involved as the amount of carryover increases. Deposition of fluid films on the walls of the system piping, and local concentration of the separated liquid, are logical conditions that might influence the sample and possibly give inconsistent results. It seems more likely, however, that the moisture carryover equivalent to the usual impurity of 1 ppm or less would be of such dispersion that this factor would be of minor significance in the region of purity with which we are concerned. That this may be true is indicated by similar impurity test results obtained at various points of sampling along the path of the steam flow.

Steam Sampling

The process of sampling, though, is always subject to suspicion. Only a very small portion of the total steam flow is sampled, and the relative proportions of liquid and steam in the sample could be affected by sampling velocities, location of sampling nozzles, and by nozzle design. With such limitations of sampling procedure, it would be illogical to expect the same impurity result with changes in rating and concentration, or to expect a variety
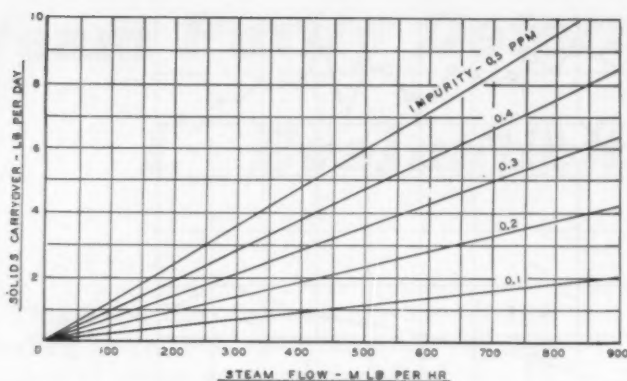
Fig. 2—Calculated solids carryover

of results from different boilers. By the same token when the impurity in steam is less than 1.0 ppm, the extremely small amount of moisture involved is so dispersed that velocities and sampling locations should have little effect on results.

Varying the sampling rate of 1–2 mmho steam generally has little if any effect on its observed conductivity value. Similarly, sampling in such unorthodox locations as the saturated header drain line will usually give steam of conductivity similar to standard sample when the steam is commercially pure at less than 1 ppm. When carryover is known to be present in the steam, sampling results are generally different at different locations and become more sensitive to variations in sampling flow and velocities.

Summing up these observations, this conclusion may be reached. If the impurity test values remain constant over changes in boiler rating, and/or boiler water concentration, there is either no boiler water carryover in the steam or it is so small that its variations have no appreciable effect on the test values. What then are we measuring? It seems likely that such test values represent dissolved gases that are not accounted for by present methods of degasification and correction, and/or accumulation of sampling system contaminations.

An immediate reaction is that if we conclude that the carryover is so small we cannot detect it, it does not explain the many cases of turbine blade deposits with steam of such assumed purity. Silica and other materials which are not readily detected by conductivity methods become involved in the question of turbine blade deposits, but even on a basis of soluble salts this question may not be too difficult to answer. Fig. 2 shows the calculated solids carryover in pounds per day for a range of steam flows of different impurity content. An impurity of 0.1 ppm from a 525,000 lb per hr boiler will deliver 1.25 lb of solids per day to a turbine. This amount of impurity adds up to 37.5 lb per month and 450 lb per year. Anyone who has scraped turbine blades to obtain samples of deposit will appreciate that only a small percentage of the estimated carryover seems to be left on the turbine. If, however, a relatively large percentage of the carryover is deposited it would take only a very small impurity in the steam to account for the amount of deposit found. Thus the concept of 0.1 ppm or less impurity in the steam is not unreasonable.

Steam Purity vs Steam Quality

There are other observations, noted over many years of testing, that tend to confirm the possibility that steam from modern boilers is much purer than conductivity tests indicate. The ratio of the conductivity of the steam sample over the conductivity of the boiler water, or the ratio of the ppm in the steam over the ppm in the boiler water, can be taken as an indication of the per cent boiler water moisture in the steam. Although there may be some question about the accuracy of such ratios, its use is justified as an analytical tool in steam testing.

Let us assume two common examples of test results to which this ratio may be applied. Two boilers of similar size, design and operating conditions, use a 100-ppm boiler water in one case and a 2000-ppm water in the second case. Both give steam impurity test values of $1/2$ ppm by accepted methods. With the 2000 ppm concentration, the actual liquid carryover is in the order of 0.025 per cent which seems quite reasonable, but in the case of the 100 ppm concentration, the liquid carryover is 0.5 per cent, a most unlikely steam quality from a modern boiler. To accept both is to imply that the liquid separating efficiency of the drum internals increases radically with increase in boiler water concentration. The inconsistency in the ratios is far too great to be accounted for by inaccuracies in the ratio itself.

If, now, we conclude that the sampling methods are reasonably reliable, that the conductivity measurements are correct, and that the steam is much purer than the measurement indicates, to what can we attribute a constant impurity test result that is relatively independent of boiler rating and boiler water concentration? It has been suggested that these values are mostly due to unremoved gases in the sample and/or sampling system contaminations. Let's study these factors and see if such sources will give a constant test value.

Contamination Factor

The contamination pickup from a sampling system should depend largely on one or more of several factors such as the material used for the sample line, condenser, etc.; the length of travel or time of contact with contaminating surfaces; and the velocity and quantity of flow. In any given sampling system, these factors will be reasonably constant and any contamination would likely be constant regardless of rating and boiler water conditions. Experience in regard to the importance of materials and length of sampling lines is conflicting. In one case, sample conductivity of 1 mmho increased to 2 mmho when the sample line was extended from drum level to operating level. In another case, very low conductivity was obtained with a long, ordinary iron pipe sampling line. Samples collected in steel epuipment have shown high iron content and samples collected in silica ware have shown high silica content. The evidence is that there is a contamination factor produced by sample line materials, that it should be reasonably constant, but that it cannot be evaluated at present.

Velocity and Quantity of Flow

The velocity and quantity of flow can similarly be factors of importance in the effect of contamination on samples. If the velocity of flow is not sufficient to sweep stagnant films from container surfaces, these films remain in the system long enough to pick up contaminations and contribute to the conductivity of the

sample. The purer the steam, the greater is such pickup and the greater the contamination error in the test result. This source of error is minimized by designing the system for sufficient velocity to keep stagnant films to a minimum and for sufficient volume of flow so that the amount of such contamination is diluted and minimized. Also, sampling systems should have no vertical flow sections or pockets unless flow velocities are high enough to keep such areas clear of liquid accumulation. In one case, sampling from such a system at too low velocity resulted in cyclic fluctuations in conductivity due to periodic clearing of accumulated liquid in a sample line pocket. At higher velocities, conductivities were constant.

Presence of Residual Gases

The second major factor influencing sample conductivity is the presence of residual gases such as carbon dioxide and ammonia. Is it logical that the presence of such gases will result in a constant sample conductivity at different ratings and concentrations? If residual gas in the sample is definitely indicated by chemical test, it is evident that further correction of the conductivity is required. Chemical tests, however, are not highly accurate at very low values and for our purpose we must assume the case where the gas appears to be absent. To demonstrate, however, that the gas effect on conductivity is reasonably constant, it will be desirable to deal with undegassed steam.

The gas content in the steam is primarily a function of the feedwater flow. The potential gas evolution from the water in the boiler has either been eliminated by a period of continuous operation or it is fixed by some equi-

librium with boiler water conditions of alkalinity and the like. Since the feedwater flow rate more or less parallels the steam flow rate, the gas content in the steam will be reasonably constant over a range of rating if the composition of the feedwater is nearly constant. Increase in makeup or condensate proportions in the feedwater will tend to change the gas contents in the steam, and variations in the relative proportions of steam flow, water flow and blowdown will often result in minor changes in outlet steam conductivity. When such effects are recognized, they can often be detected in conductivity records.

Constant Conductivity of Sample

Sampling system contaminations and residual gas effects can, therefore, contribute to a constant conductivity of the steam sample over a range of normal ratings and boiler water concentrations. In view of an absence of effect of rating and concentration on the usual conductivity value, it seems reasonable to conclude that a large proportion of the value is due to gas and contamination rather than due to boiler water carryover. Until steam impurity test results register consistent variations with changes in rating and boiler water concentration the values are open to serious question and the indications are that steam from modern boilers is much purer than present test methods can show. Many engineers recognize this situation and efforts are constantly being made to improve present methods. Until such improved methods are available, application of special test procedures and critical interpretation of results should supplement standard test methods in the evaluation of steam purity.

Business Notes

The largest international power exchange in the world was put into operation just before the close of 1953 between the **Detroit Edison Co.** and the **Ontario, Canada, Hydro** system. It took a special Act of Congress to clarify the U. S. Federal Power Act and separate permits from the Federal Power Commission, the U. S. Corps of Engineers, the Civil Aeronautics Authority and the Michigan Public Service within the U. S. A. and similar authorizations on the Canadian side from various governmental and regulatory bodies to make the exchange possible. The interconnection involving between 300,000 and 400,000 hp will provide safeguards for essential power service in emergency, as well as economic benefits from surplus hydro output in high water periods and steam-generating capacities during low water seasons.

Swartwout Co. announced that after January 1, 1954, all sales and service matters of its Automatic Control and Power Plant Equipment divisions would be handled from its Los Angeles, California, office.

The Development of Nuclear Power
for Peaceful Purposes*

By DR. HENRY D. SMYTH

U. S. Atomic Energy
Commission

Dr. Smyth discusses results of "boiling experiments" at the National Reactor Testing Station in Idaho and outlines proposals for the recently announced 60,000-kw pressurized water reactor slated for Duquesne Light Co. system, plus four other different designs yet to be settled as to location and final ratings.

THE structure of modern industrial society depends on plentiful supplies of energy. There is never enough. We are always seeking new sources. Yet we have not tapped the most generous sources of energy that nature has supplied to us—the winds, the tides, the rays of the sun. We have not yet learned how to harness these great natural forces.

Fifteen years ago a new natural force was discovered, the fission of uranium. Within the first two months of 1939 the idea of uranium fission was suggested, communicated, proved experimentally and published. The speed and importance of this discovery constitute one of the most spectacular events in the history of science. It involved men of many nations, free communication, high imagination and precise experiment.

In a world at war, the potential use of nuclear fission in bombs meant that vast sums of money were soon available for its exploitation. In 1945, only six years later, an atomic bomb marked the end of the second World War.

We are now engaged in an effort to harness this same atomic energy for peaceful purposes. It is a great effort and indeed should be so, for success in it may materially change the lives and conditions of men. The accident of history has placed the major responsibility for this effort on the Government of the United States. As its agent, the Atomic Energy Commission has brought together an array of scientific and engineering talent never before equaled. Private industry already is carrying a major share of our enterprise under contract to the Government and is now becoming more and more active on its own initiative. This is as it should be.

Those of us engaged in this effort believe we shall be successful. We are so confident of success that we do not begrudge the years and the skill and the millions of dollars that are being spent to make available to man the kind of energy that heats the stars. But the road to success will be a long one. We know that it will have many dead ends

and wrong turnings and many dull and dreary stretches. The barriers to be surmounted or by-passed are formidable.

By now we think we know what these barriers are, what kinds of problems have to be solved if nuclear power is to be significant in our economy. We should know these problems, for it is now fifteen years since nuclear fission was discovered, ten years since the first large-scale nuclear reactor was started, and five years since the Atomic Energy Commission announced its first program of nuclear reactors aimed at power. Energy from nuclear power plants will be just like energy from coal burning power plants. Except for special purposes, the sole criterion of comparison will be cost.

Let me outline the problems we foresee. The problems of reactor development today are best explained in terms of those which faced the designers

of the first great reactors at Hanford. These problems are so fundamental that they will continue to be of major importance even though the emphasis may shift from time to time. Once I have defined the problems, I shall outline our present state of knowledge and the next major steps we are planning for their solution.

The General Problems

Let me recall to you the three major facts of nuclear fission. They are: first, that enormous amounts of energy are released; second, that the products of fission are radioactive; and third, that fission is caused by neutrons and results in the production of further neutrons thereby making a chain reaction possible.

These basic facts confront the designers of reactors with a series of technical questions which can be grouped in five general areas. These general areas
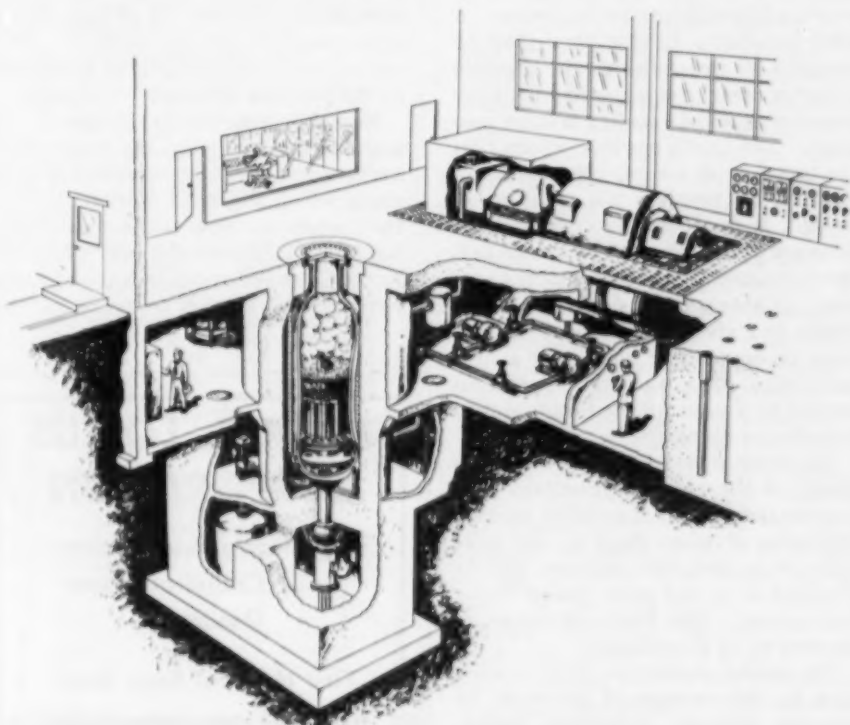
Experimental boiling water reactor referred to by Dr. Smyth in article above and Dr. Hafstad, see editorial, p. 37. Tall, cylindrical tank is the reactor assembly with water being converted directly to steam for use in turbine. Holes in floor, right, safely store radioactive, partly used fuel elements from reactor pending their final disposal

which have to be considered are, first of all, what we call neutron economy; second, the effects of nuclear radiations; third, heat transfer or removal; fourth, control and instrumentation; and fifth, chemical processing of fuel both before and after it goes into the reactor. Let me go into some detail about these five areas.

1. Neutron Economy. It is evident that the first requirement of a nuclear reactor is that the nuclear chain reaction shall occur. In other words, if a uranium nucleus in a structure containing uranium does undergo fission, it must produce neutrons in sufficient quantity to cause other nuclear fissions in the vicinity and to set up a self-propagating nuclear chain reaction. Actually the number of neutrons produced by a single fission is not very large. On the average, for every neutron used up in producing a fission about two and a half new neutrons are released, a net gain of one and a half neutrons per fission. At first sight, this would appear plenty to produce a multiplication of fissions. Unfortunately, from the point of view of neutron economy, all the neutrons produced in a single fission are not absorbed in uranium 235 to produce additional fissions.

There are, in fact, four things that can happen to the neutrons that are produced in the fission process. First of all since neutrons are extremely penetrating, they may simply escape to the outside environment. A second way in which they disappear is by capture by uranium 238 without causing fission. A third possibility is that they may be captured by impurities in the uranium or by the structural materials that have to be introduced for cooling or other purposes. The fourth possible process that can occur is, of course, the capture of neutrons by uranium 235 resulting in fission. If the fourth process produces more neutrons than are lost by the first three processes, the chain reaction occurs. Otherwise, it does not. Evidently, in a given arrangement the first three processes may have such a high probability that the extra neutrons created by fission will be insufficient to keep the reaction going.

One obvious way to reduce the probability of the escape of neutrons is to increase the amount of uranium present. The more uranium there is, the more likely it is that the neutrons will be absorbed in it and cause fission rather than escape. This leads, of course, to the concept of critical mass.

The second process we need to minimize is the capture of neutrons by uranium without producing fission. There are several things that can be done to minimize this process. Two of them depend on the great effect which the speed of the neutrons has on the probability of their absorption in uranium

238. This probability is reduced by using a slowing down material, called a moderator, and arranging the uranium in a lattice. Another way to reduce nonfission capture by uranium is to eliminate part or all of the uranium 238 isotope, since it contributes very little to the fission process and does absorb many neutrons. Of course, in the Hanford reactors, this was not desirable because one of the objectives of the Hanford reactors was to produce plutonium by absorption of neutrons in uranium 238.

To reduce the third process, the nonfission capture of neutrons by impurities or structural materials, requires that the uranium itself be very highly purified in the first place and that structural materials be used which have a low capacity for the absorption of neutrons. This last consideration puts many restrictions in the path of the designer of a nuclear chain reactor.

2. Nuclear Radiation Effects. The effects of nuclear radiation have several aspects that the designer needs to keep in mind. Perhaps the most important one technically is the fact that the constant bombardment of structural materials and of uranium itself causes changes in their properties. A piece of uranium, a piece of steel or aluminum in a nuclear reactor is continually bombarded by neutrons, by gamma radiation, and to some extent by other nuclear radiations. The result of such bombardment may be a change of shape, an embrittlement, a change in thermal conductivity, or of almost any other property of the material. The rate of corrosion of a material is affected by the presence of nuclear radiation.

Nuclear radiation is dangerous to health. Consequently, the whole reactor structure must be surrounded by a shield which will not be penetrated by the neutrons and other radiation. Radiation is present not only while the reactor is running, but induces a lasting radioactivity in the materials of the

reactor. In particular, fuel elements in the reactor become highly radioactive, and when they are unloaded for chemical processing, they have to be handled by remote control. It is unsafe for any personnel to handle them directly. Similarly, maintenance must be held to an absolute minimum, and actual direct access of the operators to the heart of the reactor must be avoided.

3. Heat Transfer or Removal. The principal interest in establishing a nuclear reaction is because the fission processes release such enormous amounts of energy, millions of times the amounts of energy released in chemical reactions in corresponding amounts of material. To be sure, the Hanford reactors were not designed for the purpose of producing energy but for the purpose of producing plutonium. Nevertheless, the production of large amounts of energy is inescapably associated with the fission process, and therefore, the designers of the Hanford reactors had to provide some means of removing that energy. It was a simpler problem for them than for the designers of a reactor intended to produce energy. The Hanford designers had merely to get rid of the energy in some way.

The designers of a power reactor must extract the energy in a form which can be put to use. Nevertheless, many of the problems are the same. They differ from ordinary heat transfer problems for reasons that have already been suggested; namely, that the choice of materials is limited by neutron economy, that corrosion effects may be enhanced by the radiation present, and finally that the replacement of parts is difficult or impossible because of the health dangers involved. In a power producing reactor, the temperature should be as high as possible so that the heat energy removed can be converted into useful power efficiently. This is a real difficulty as we shall see later on and is one point where the Hanford designers had a considerable advantage.

4. Control. When the first reactors were designed, the question of control was a very critical one. No one knew very certainly whether or not it would be possible to prevent the reactor from running away with itself. We do not want to have a reactor heat up to the point where it will melt and destroy itself. We wish to avoid this for two reasons: first, we don't want to lose the reactors; and second, we don't want to spew radioactive material all over the countryside. By now, we have had enough experience so that we are not very concerned about essential difficulties of control. We are perfectly sure that we can build a reactor which we can control. In fact, as I shall mention later, some types of reactor are self-controlling. There does remain, however, a problem of convenience, effi-

ciency and cost in designing the proper controls to start, stop or maintain at a desired operating level the nuclear chain reaction.

5. *Chemical Processing of Fuel.* Ideally, we would like to put into a nuclear reactor a certain amount of uranium and leave it there until all the uranium had been converted into heat energy and fission products. If that were possible, we would be concerned with chemical processing only in preparing the fuel. Unfortunately, the difficulties both of neutron economy as affected by the growth of fission products and of the corrosion or radiation damage of structural materials or fuel elements make it quite out of the question to consume more than a fraction of a nuclear charge in any known design of reactor. After a certain length of time—and one of the problems in the design of reactors is to make that length of time as great as possible—it is necessary to remove the fuel. It is too valuable to throw away, since it will probably still contain some ninety per cent or more of the fissionable material. Consequently, we have to reprocess it chemically, separating out the fission products, and refabricating the uranium into new fuel elements. This turns out to be one of the most costly processes in the whole business of operating a reactor for power.

I believe it is possible that the nuclear power industry will stand or fall economically depending on the success which chemists and chemical engineers have in developing cheap processes for purifying and refabricating nuclear fuel.

The Hanford Reactors

I have been speaking of the general technical problems of reactor design. To be more concrete, let me recall briefly in specific terms how these problems are met in the Hanford reactors.

For neutron economy, the reactor is large. It uses graphite as a moderator, and the natural uranium fuel elements are arranged in a lattice. Both graphite and uranium are very highly purified. Cooling channels and protecting coatings of the uranium fuel elements are aluminum of minimum dimensions.

To shield operating personnel, the reactor is surrounded by heavy composite walls and all control and operation are from outside the shields. To reduce corrosion of the aluminum, the cooling water is purified and the temperatures held relatively low. To avoid corrosion or distortion of the uranium, it is canned in aluminum and not left in the reactor very long.

Heat is removed by large volumes of Columbia River water with relatively low exit temperature. The water is then held in retention basins before returning to the river.

Control is by neutron absorbing rods that move in and out of the reactor.

The position of the rods is recorded at the control desk and varied by the operators or automatically in response to instruments

Chemical processing by a solvent extraction process is done in a separate plant to which the fuel elements are transported in shielded railroad cars, with all operations remotely controlled.

Fundamentally, it is the low exit temperature of the cooling water and the short life of the fuel elements that make this plant impracticable as a power source.

Breeding

Uranium 235 is the isotope of uranium in which fission occurs most readily. Unfortunately, it is present in natural uranium only one part to 140. Natural uranium is none too plentiful, and to be able to use only seven-tenths of a per cent of it is frustrating. Neutrons absorbed in the other uranium isotope, uranium 238, lead to the production of plutonium and plutonium is readily fissionable. This fact early suggested the possibility that a reactor could simultaneously produce heat energy from the uranium 235 in natural uranium, and produce plutonium from the uranium 238, and that then the plutonium could be used as fuel for further production of energy. It was even suggested that the plutonium produced might be greater in quantity than the uranium 235 burned up. Such a process is called a breeding process since more fuel can be produced than would be burned.

This is, of course, a very fascinating idea. It turns out, however, that it may not be so very important whether actually more material is produced than is burned. It is obviously possible to produce some plutonium, since that is what the Hanford reactors are for and it should be possible to take that plutonium and use it as fuel for power reactors. Whether the amount of plutonium produced is slightly less or slightly greater than the amount of uranium 235 burned up is not very important. We do, however, make a distinction in nomenclature whereby we call a reactor that produces plutonium in smaller quantity than uranium burned, a converter, and one where the quantity produced is greater than that of uranium burned, a breeder. In either case, it should be possible eventually to convert the fission energy of both isotopes of uranium to useful power. In the case of the converter, there would be some loss; in the case of the breeder, the losses in the reactor would be zero, but in either case, there will be losses in chemical processing so that the difference is not very significant. The difference, however, between using just the uranium 235 and eventually using all of the the uranium in natural uranium is enormous and may well make the difference between an ample supply of

nuclear fuel for many years to come and a rather scanty one.

The First Reactor Program

When the Atomic Energy Commission took over the plant and equipment of the Manhattan District in January 1947, the problems that I have been reviewing were already clear. Although the Commission's first responsibility was to prosecute the atomic weapons program with vigor, it soon turned to the possibility of atomic power, both for special military purposes and for ultimate peacetime uses. Early in 1949, Dr. Bacher, my predecessor as the scientific member of the Commission, made a speech in which he outlined the ways in which the Commission was attacking the problems I have reviewed. Essentially, the program consisted of a plan to build four major reactors. Let me describe three of these that have been finished at our Idaho Test Site and why they were built.

The first of them was the so-called materials testing reactor, MTR. It was aimed primarily at getting information on the effects of radiation on uranium fuel elements or other materials that might be used as tubes for cooling water, or as coolants, or containers for uranium fuel elements. The object of this reactor then was to provide very high intensity radiation in a machine so designed that many experimental samples could be placed in it. It has now been running for about two years, and it has in fact proved exceedingly useful. Incidentally, it also was a novel kind of reactor and therefore was in itself a step toward the development of new types of reactors.

The second reactor built at Idaho was the so-called experimental breeder reactor, EBR. As the name implies, it was specifically aimed at demonstrating whether or not breeding was possible. It has demonstrated that breeding is possible and has had a number of other incidental interesting results.

The third reactor was a special purpose one aimed at providing power for a submarine. You have heard a great deal about that one and about the submarine in which a similar reactor is now being installed.

In all three of these reactors, the neutron economy problem was solved by using uranium from which much of the uranium 238 isotope has been extracted. Whether or not in the long run, this is the kind of reactor we will build for power purposes will be largely a question of economics. Personally, I doubt it, but I do not doubt the wisdom of having built these three reactors and the value of the results we have obtained from them.

A more modest undertaking initiated later is the homogeneous reactor experi-

ment at Oak Ridge. From the atomic point of view, the homogeneous reactor is misnamed. In reality, one can think of it as a lattice where the spacing is very small and the size of the fuel elements is of atomic dimension. To put it more simply, and in terms that will be more familiar to you, the homogeneous reactor is a solution of uranyl sulfate in water. The water serves as the moderator, and the uranyl sulfate molecules serve as the fuel elements in which the chain reaction is set up.

The immediate and obvious advantage of the homogeneous reactor is that fuel fabrication and processing is enormously simplified. The solution is pumped continuously through the reactor chamber and then cooled in outside heat exchangers, and some of it can be continually led off for purification and then re-introduced into the circulating stream of combined fuel and moderator. One of the interesting features of the homogeneous reactor is that it turns out to be self-regulating. As the temperature of the reactor rises, its reactivity decreases and therefore it controls itself. One difficulty that was anticipated in the homogeneous reactor was that the water itself would be dissociated by the radiation. This does occur, but it has been found possible to recombine the hydrogen and oxygen formed without too great difficulty.

In addition to the results obtained with the three reactors I have been discussing, and the homogeneous reactor experiment, there has, of course, been an extensive program of study of the various associated problems in the laboratory. These range from fundamental studies of what causes radiation damage, or of the absorption probabilities of various materials for neutrons of various energies, to component testing in heat loops, and experimental fabrication of fuel elements. Some of these studies use the various low-power research reactors that have been built.

One of the most interesting experiments that has been done was carried out last summer at the Idaho Test Site by Dr. Zinn, director of our Argonne Laboratory, and his associates. We had long worried about what would happen to a water-cooled reactor if the flow of water should be cut off. We were afraid if the water supply was cut off or if the temperature of the reactor rose too rapidly boiling would occur and that this might have disastrous results. Dr. Zinn decided to make a direct approach to this problem and built a small reactor with the deliberate intention of producing boiling. When it was set up at the Idaho testing station, it had an arrangement in it which suddenly ejected the control rods so that the power generated by the chain reaction went up in a fraction of a second from a few watts to many

thousands of watts. This had the expected effect on the water. It boiled. It boiled so violently in fact that it was ejected from the reactor in a small geyser. Repeated trials showed that in every case the boiling reduced the power of the reactor so rapidly that no serious damage was done.

This particular experiment illustrates very well the reasons for choosing an isolated area as a site for experimental reactors. It was not only that some of the reactors might be inherently dangerous, but it was felt that an experimental reactor, one built primarily for the purpose of obtaining information, should be operated to extremes, and that it was desirable to have them in an isolated location for that reason. In other words, if you want to get as much information as you can out of a reactor, you need to push it to the point where it might conceivably run into trouble.

Past Results and Present Status

Let me summarize some of the major results that we have obtained in the last five years either directly from the reactors we have built and operated or from laboratory work. I will take them in terms of the five general areas that I enumerated at the start. So far as neutron economy is concerned we have learned a great deal about the probabilities of various nuclear events, including the relationship between the probability of fission and the energy of the neutrons. (This, for example, was tested in the experimental breeder reactor.) We have found that we can use a number of different substances as moderators, specifically beryllium, light water, and heavy water in addition to the familiar graphite.

As to the effects of radiation, the MTR has, of course, been of the greatest value as one might expect since it was designed for that purpose. But we also have the benefit of studying the fuel elements that have been in the EBR and in the submarine thermal reactor. These, too, have been valuable. We have made a great variety of alloys and have tested various fuel elements. In particular, the submarine thermal reactor has shown that fuel elements sheathed in zirconium will resist corrosion and radiation effects over considerable lengths of time and represent a great improvement over the aluminum sheathed fuel elements in the Hanford reactors. Radiation effects have also been studied in a variety of coolants including sodium and heavy water.

In the matter of heat transfer we have found we can remove the heat from a reactor by circulating molten sodium-potassium alloy through it. This is the system of heat removal used in the EBR. We have also done a great deal of work on pure sodium as a possible coolant and are using it in the

second type of submarine reactor now under construction. We have also found that we can use a cooling system of pressurized water. This is the system used in the submarine thermal reactor. We have run reactors at much higher temperatures than we were ever able to run them at Hanford, and, therefore, we have moved in the direction of efficient use of the energy from nuclear fission.

As to control and instrumentation, the most striking results have been those already mentioned where we have found that certain types of reactors are in fact self-regulating as a result of boiling or near boiling as the temperature rises. The only other result I will mention is the use of hafnium as a material for control rods. Hafnium is present as an impurity in zirconium and has to be removed before zirconium cladding can be used for fuel elements because it absorbs neutrons. For the same reason it is very useful as a control material.

In the matter of chemical processing, perhaps it is fair to say that most of the work has been accomplished in the laboratory, although we have had experience with actual processing of the various types of fuel elements in the new reactors, none of which is exactly like those at Hanford. We have also proved that the homogeneous reactor will work, at least on a small scale, and we, therefore, know that that is one direction in which to hope for improvement.

In the matter of costs, we still have much work to do. None of the reactors that we have actually put up is cheap, either to build or to operate. The submarine thermal reactor probably costs somewhere around fifteen hundred or two thousand dollars per kilowatt to build, which is to be compared with the cost of a modern steam plant somewhere around a hundred and eighty dollars per kilowatt. But the submarine thermal reactor does prove one over-all major result; namely, that it is possible to build a reactor for the production of power that will run for at least reasonably long times continuously and efficiently.

Unanswered Questions

The fundamental question still to be answered is whether a power producing uranium reactor can be built which will compete with other sources of energy. The answer to that question will be found in the choice of some one of the kinds of reactors we have already built or thought about. None of them has yet been proved to be the ideal or even the best choice. The homogeneous reactor, for example, does simplify chemical processing, but it requires enriched fuel and it is not yet certain that the corrosion problems can be solved.

The breeder has not yet been proved on any large scale so that we do not know at all how expensive that may be. The submarine thermal reactor uses such expensive materials for cladding the fuel elements that it is almost certainly not competitive, even though we may be able to produce zirconium at lower and lower costs. It also uses enriched material. And so it goes all through the list.

Proposed Five-Year Program

In the last few months we have been reviewing the results that we have obtained up to the present time and planning what would be best to do over the next few years in order to arrive at an economical solution of the problem of nuclear power. We have decided that there are six programs that we should pursue. One of these is the general program that we must obviously continue, the program of research on fundamental properties of materials, on nuclear reactions, on components that might go into the reactors of the future and on chemical processes. This work will be continued principally in our Argonne and Oak Ridge laboratories. In addition to this general research and development work, we wish to build five reactors of varying size and cost. The Commission has recently submitted to the Joint Committee on Atomic Energy a special report on the reactor program prepared at the request of the Committee.

The first of these reactors in our new program has already been publicly announced. It is the so-called PWR reactor which is designed to generate at least sixty thousand kilowatts of electric power. It will use slightly enriched uranium as fuel, ordinary water as a moderator and coolant. The reactor will be operated under reasonably high pressure and temperature, not nearly so high as are used in modern steam plants, but as high as we feel safe in terms of our present knowledge. Specifically, the water in the reactor will be under two thousand pounds per square inch pressure and at a temperature between 500 and 600 F. Steam will be delivered to the turbine at about 600 pounds per square inch. The temperature is limited by the corrosion of the fuel elements and piping and container, and the pressure is limited by the strength and size of the vessel in which the reactor must be contained. One of the difficult problems in this reactor will be that of getting control mechanisms to operate in a high-pressure vessel. Principally, we hope to learn from this reactor how such a plant may stand up under ordinary operating conditions of central station electric power plant and how much it costs to build and operate it. We have no expecta-

tion that this reactor will produce power as cheaply as a modern coal burning plant, but we hope to learn how costs can be cut in later plants.

The second new reactor which we wish to build is a breeder of intermediate size. It will not be of direct interest from the point of view of economic power, but it will be much larger and much more nearly a power producing, continuously operating reactor than the small experiment we have been running out in Idaho. The scale-up planned is from 1400 to 62,500 kilowatts of heat, and from 170 to 15,000 kilowatts of electric power. Temperatures and steam pressure will be increased to values appropriate to a full scale power breeder reactor. Auxiliaries such as pumps, heat exchangers, valves, etc. will be of sizes suitable to a full scale reactor.

Our third step is based on the boiling experiment that I have already described. It will be an attempt on an intermediate scale actually to use boiling of the water as a method of heat extraction. We hope in this way to get a very cheap method of getting the heat out of the reactor and possibly of eliminating one step between the coolant in the reactor and the turbines which turn the generator. It is planned to feed the steam generated in the reactor directly to the turbines. Present plans call for 20,000 kilowatts of heat and 5000 kilowatts of electric power.

The fourth reactor which we intend to build is a larger version of the homogeneous reactor. Again, it will be a step in the direction of a practical power producing unit and should give us information about corrosion, chemical processing, and operating conditions that cannot be obtained with the small machine now in use at Oak Ridge. Present specifications call for only 3000 kilowatts of heat in this reactor experiment compared to 1000 in the present experiment. The next step, already planned, calls for 65,000 kilowatts of heat in a homogeneous reactor which will breed uranium 233 in a blanket of thorium surrounding the chain reacting core.

The fifth reactor experiment which we plan to build is a little different from any that I have described. I have mentioned that the breeder reactor uses sodium-potassium alloy as a coolant. You all know that the Hanford reactors use graphite as a moderator. We hope to be able to combine these two materials, getting the advantage of high temperature without high pressure from the sodium coolant. To test this combination, we will build a reactor generating about 20,000 kilowatts of heat but without any electric generating plant attached.

In addition to these new proposals, we shall continue several other programs

already under way. These include the so-called intermediate submarine reactor now under construction at West Milton, New York, near Schenectady, and the development of a reactor to propel aircraft. Though the aims of both of these projects are special, they will undoubtedly contribute to the general technology.

Costs

It is evident that we can build power plants which will convert the energy released in nuclear fission into electrical energy to be fed into transmission lines. The question that has not been answered and may not be conclusively answered even by the program I have outlined is whether this power can be produced cheaply enough to be of general use. The Atomic Energy Commission believes that it can be done and this is the opinion also of the several private industrial groups who have been studying the problem for several years at the invitation of the Commission. At present, the power delivered by the submarine reactor at our Idaho plant costs about ten times as much as it would if we bought it from the Idaho Power Company. From this figure you can see that it will require all the ingenuity of our staff, our contractors and private industry working together to get costs down, but it is reasonable to assume that eventually this will be done.

Industrial Participation

These private industrial groups I have mentioned are interested in more than just cost studies. They have assigned able members of their staffs to design studies of nuclear power plants and in some cases are doing considerable amounts of research at their own expense. But it is a mistake to think that private industry can or will pick up the burden of development of nuclear power plants in the present state of the art. It is a field in which knowledge and competence are still largely confined to Government laboratories and in which the financial risks are still too great for private industry to carry alone.

The Commission hopes for greater and greater participation by industry both technically and financially and for a gradual transfer of the nuclear power part of the Commission's responsibilities to private enterprise. To discuss the many problems of such a transfer would need another speech. Personally, I feel they are just about as difficult as the technical problems of getting cheap nuclear power. Time, money and thought will be needed for both sets of problems. I believe they can be solved.

Conclusion

To establish a nuclear power industry in this country will be a great achieve-

ment. If power becomes cheaper and more plentiful, our material standard of living will be raised. In other countries the effect may be even greater. By the accident of history the first use of this great new discovery has been in the development of weapons of war, weapons of appalling magnitude. The nations of the world have today the means to destroy each other. They also have, in this same nuclear energy, a new resource which could be used to lift the heavy burdens of hunger and poverty that keep masses of men in bondage to ignorance and fear. Toward this peaceful development of nuclear power we have, all of us, a high obligation to work with all the ingenuity and purpose we possess.

Combustion Engineering Reports Personnel Changes

Martens H. Isenberg, president of Combustion Engineering, Inc., has announced the appointment of R. C. Ulmer as head of the Research Department, succeeding B. J. Cross who has reached retirement age. Mr. Cross has been appointed Research Consultant.

Dr. Ulmer, a graduate of Ohio State University where he also received his doctorate, has had considerable utility experience. He was employed by the Columbus & Southern Electric Company in 1930 and subsequently by The Detroit Edison Company where his activities centered in the chemical division of the Research Department. In 1945 he became technical director of the Industrial Department of E. F. Drew & Co., Inc., in which capacity he was responsible for research and development of water-treating products. He joined Combustion Engineering in January 1953 and has been concerned with chemical problems of the Nuclear Energy Division.

Mr. Cross, who succeeded the late Dr. Henry Kreisinger as head of the Research Department in 1946, was graduated from Colorado College. Following several years in mining operations in the West, he joined the staff of the U. S. Bureau of Mines in 1917 where he was engaged in fuels research. He was employed by Combustion Engineering in 1920 and was identified with early applications of pulverized coal to power boilers, notably those at Oneida Street and Lakeside Stations in Milwaukee. In his work with the Company Mr. Cross has made a number of outstanding contributions to advance boiler feed-water studies, steam sampling methods, temperature measurements and fuel-burning problems.

New Catalogs and Bulletins

Any of these may be secured by writing Combustion Publishing Company, 200 Madison Avenue, New York 16, N. Y.

Remote Bulb

A variety of models, ranges and control forms characterize the material coverage in the 44-page Industrial Div., Minneapolis-Honeywell Regulator Co. Catalog 6709 on remote bulb thermometers. They are actuated by mercury, vapor or gas pressure changes. There are indicating models and one, two and three-pen recorders plus remote bulb thermometer models with various types of pneumatic and electronic controls and timed program controls with one or two integral cams or with a motor-driven index.

Soot Blowers

Probably the most widely used of all sootblower types, the fixed position, rotating element, soot blower design makes up the subject matter for the 8-page bulletin No. 1137 of Diamond Power Specialty Corp. The bulletin portrays the various uses of the company's Model G9B on boilers, superheaters, reheaters, economizers, heat exchangers and oil stills. Model G9B, electric or air-motor driven, is available in three pressure ranges, the last of which goes up to and includes 1500 psi. A number of its advantages, its construction features and adaptability to automatic sequential operation are brought out in the bulletin.

Industrial TV

Remote control of equipment in power plants has led to rapid adoption of new techniques. One such is industrial TV. A recent 8-page bulletin by the Industrial Products Division of the Radio Corporation of America cites the advantages TV has for centralized observation of power boilers, at safe, convenient furnace locations and yet result in accurate pictures of boiler furnace conditions under simple operating controls. The bulletin also develops the manufacturer's theme of centralized planning, installation and service.

Temperature Control Systems

Simple or complex temperature control problems in industrial process applications require a background of available sensing elements, a familiarity with industry control terminology, and a knowledge of the rules to follow in selecting the proper method of temperature control for process characteristics

Power Plant Cleaning

A 44-page booklet by Oakite Products, Inc., entitled "How to Make Power Plant Cleaning Easier" spells out in step-by-step fashion the necessary procedure and the specific company products to employ in cleaning various of the more common power plant devices such as surface condensers, fuel oil preheaters, lube oil coolers.

Differential Pressure Transmitter

An all electronic system of differential pressure transmission, the company's Autronic Type D2T design, is described in the 4-page bulletin, A-707-A. This bulletin is well illustrated with hookup and schematic diagrams, phantom cutaway views and dimensional diagrams, put out by Swartwout Co.

Welding End Specifications

High-pressure, high-temperature service has made the practice of welding valves into lines more and more prevalent. With this greater use has come a definite need for dimensional standardization. Edward Valves, Inc., has published the 4-page bulletin, 507, listing socket welding end and butt welding end dimensions approved by the American Welding Society, to help in spreading standardization data. Socket welding end dimensions are given for valves 2 in. and smaller and butt welding ends for pipe sizes from $2^1/_2$ to 16 in.

D-C Indicating Instruments

Portable d-c indicating instruments, DP-12, accurate to of one $1/_2$ per cent, and Type DP-11, accurate to $1/_4$ of one per cent, feature the 8-page bulletin, GEC-979A, now available from General Electric Co. The DP-12 instruments are held particularly applicable for laboratory use as well as for field service in checking portable or switchboard instruments of lower accuracy on control panels. Performance data, specifications, ordering directions as well as price information are carried in the bulletin for both models.

Oil and Gas Burners

Principles involved in the selection and application of various oil and gas burners for single fuel or a combination of both gas and oil, for either standard range or wide capacity range operation,

make up the new 28-page bulletin, OB-53, now announced by The Engineer Co. This bulletin makes an excellent reference catalog with its conversion table for approximate relationships between quantity of oil burned, boiler capacity, and air required.

Temperature, Pressure Relief Valves

The function of relief valves, both temperature and pressure, for hot water storage heaters is described in considerable detail in a booklet, "Your Handbook on Temperature and Pressure Relief Valves" now available through A. W. Cash Valve Mfg. Corp. The American Gas Assn. and the ASME Code requirements are discussed and a list of do's and don'ts provided.

Flexible Tubing

The scientific application of flexible tubing for air, oil, gas, steam and volatiles comprises the material for an 8-page illustrated booklet, entitled Flexineering, put out by the Penflex Co. The manufacturer's various products are catalogued and pictured as well as a few selected application photographs.

Check Valve

Specially designed, air compressor discharge line check valve, the Airchek, is described in a 2-page bulletin, No. 509-D, released by the Pennsylvania Pump and Compressor Co. The bulletin gives an exploded view of the air cushion valve, summarizes the advantages of it and further explains its construction, application and maintenance.

Magnetic Amplifiers

Current and potential transductor magnetic amplifiers feature the 8-page Westinghouse Electric Corp. booklet, TD 52-601. A definition of magnetic amplifiers is given and an explanation of their operating theory. Application specifications are included to establish terminology for operating characteristics. This information specifies conditions needed for proper operation and, in general, explains the effect of deviations from the specified conditions.

Storage Heaters

Hot water storage heaters of all sizes and designs manufactured by the Patterson-Kelley Co., Inc., appear in the new Catalog No. 18, which outlines and locates the standard complement of tappings. The selected locations and standard fittings are said to be the result of field experience and operation over a long period of years. Extremely helpful installation suggestions as well as a few suggested piping diagrams add to the value of the release for field applications.